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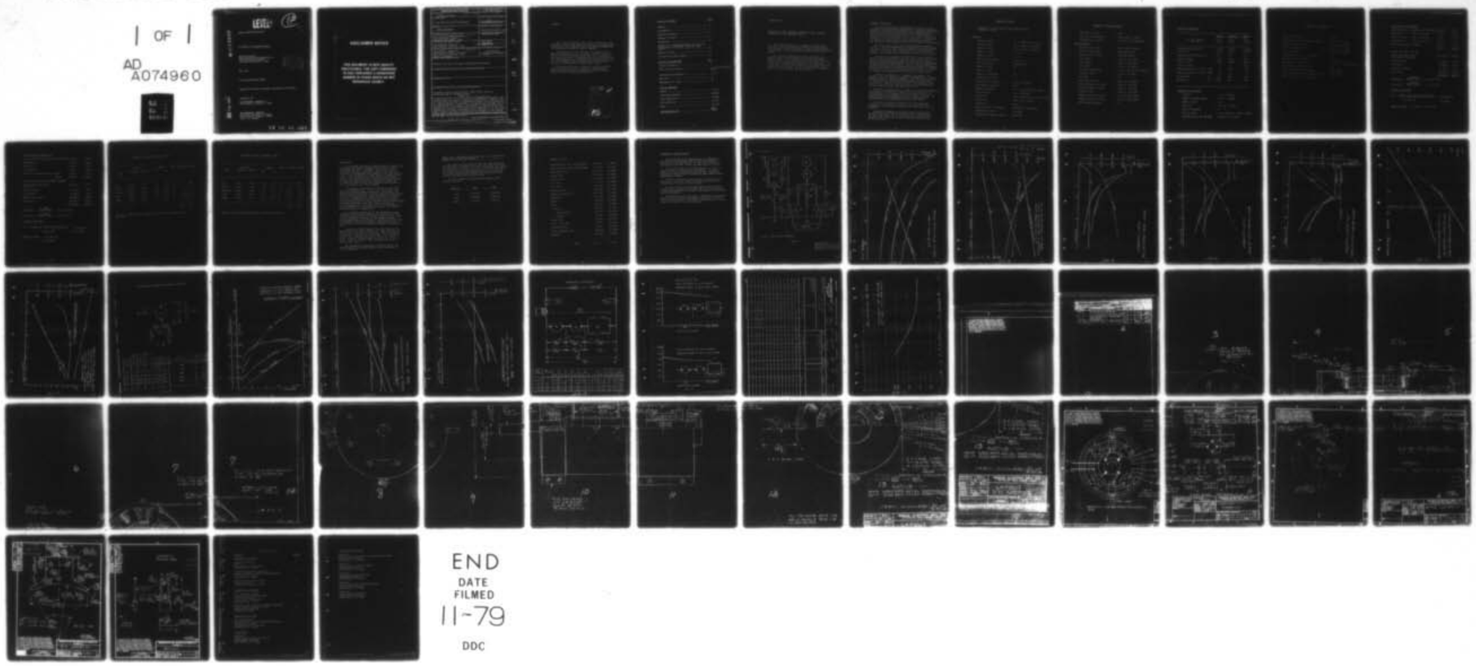

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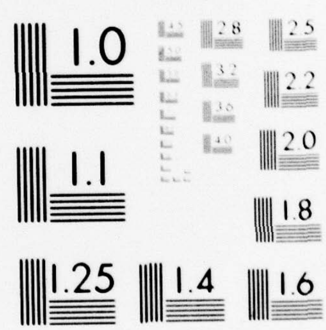
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LEVEL II

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Report DAAK70-78-C-0044

AD A074960

# DC TEST RIG PROPULSION MOTOR


Sylvain Garnett
Bogue Electric Manufacturing Co.
100 Pennsylvania Avenue
Paterson, New Jersey 07509




May 1979

Final Engineering Report

Approved for Public Release; Distribution Unlimited



Prepared for

USA MERADCOM, DRDME-PE-1
Fort Belvoir, Virginia 22060

USA MERADCOM, DRDME-EA
Electrical Equipment Division
Fort Belvoir, Virginia 22060
Attn: E. Reimers

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## REPORT DOCUMENTATION PAGE

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DC MOTOR, SERIES FIELD WITH AUX. SHUNT FIELD; ELECTRIC PROPULSION FOR DC CHOPPER CONTROL.

at This project's mission was to at

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) DESIGN, CONSTRUCT AND EVALUATE TWO HIGH SPEED DC PROPULSION MOTORS WITH A NOMINAL RATING OF 10HP @ 6000 RPM AND AN INTERMITTENT RATING OF 20HP @ 3000 RPM AT A MOTOR WEIGHT OF 95LBS/UNIT. THE MOTORS ARE DESIGNED FOR USE IN CONJUNCTION WITH EITHER A CONVENTIONAL DC CHOPPER MOTOR CONTROLLER, OR AS A DUAL MOTOR DRIVE IN CONJUNCTION WITH A TWO PHASE, SEQUENTIALLY SWITCHED DC CHOPPER MOTOR CONTROLLER. THE AUXILIARY SHUNT FIELD IS USED TO SYNCHRONIZE SPEED BETWEEN THE TWO MOTORS AND TO ASSIST THE SERIES FIELD DURING THE REGENERATIVE BRAKE MODE.

SUMMARY.

This report describes the design, construction, and evaluation of two high speed D.C. motors for a propulsion application with a nominal rating of 10HP at 6000RPM and an intermittent rating of 20HP at 3000RPM.

The objective of the work done by Bogue Electric Manufacturing Company was to design, construct, and test two D.C. propulsion motors which were to be compatible with a multiphase D.C. chopper-motor drive, described in the IEEE Transactions On Industry Applications, Vol. IA-8, No: 2, March/April 1972, pp 136-144, entitled "Design Analysis of Multiphase DC Chopper Motor Drive".

The motors also had to interface with an existing electric propulsion test rig design, originated by Barber-Nichols Engineering Company, Arvada, Colorado, which limited its envelope dimensions.

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## LIST OF DRAWINGS

## INTRODUCTION.

### DESIGN OF A 10HP, 6000RPM, CONTINUOUS 20HP, 3000RPM INTERMITTENT DUTY TRACTION MOTOR.

The design is based on a compromise between good efficiency and low weight-two conflicting requirements. Any reduction in electro-magnetic weight causes a decrease in efficiency and any increase in efficiency increases weight.

The electric loading and current densities are based on values extrapolated from previous designs of similar units. As it turned out after testing, the limit in the design was not temperature or efficiency but commutation. Considerable difficulty was experienced due to the fact that only two commutating poles were used in order to save weight. We will discuss this in greater detail in a later section of this report.

## GENERAL DISCUSSION.

The solid state control methodology utilized in conjunction with these motors requires that each motor contains a series field which is supplanted by an auxiliary shunt field. The auxiliary shunt field assists in the recuperation of energy during braking, whereby the series field usually remains in circuit and returns energy to the source during the freewheeling operating mode of the controller. In addition, the auxiliary shunt field controls speed balance between the two motors and provides steering angle control if necessary.

As can be seen on the motor interconnection diagram in Fig. 1. the two armatures are connected in series, whereas the series fields of the respective motors are connected in parallel. By sequentially switching the paralleled series fields, the armature current becomes twice the field current.

The special requirement for this motor is to provide a series field winding which furnishes 85 to 100 percent of the required ampere-turns with only half the armature current, while the remaining requirements for magnetic flux excitation is provided by the shunt field. Since it was necessary to pretest this motor as a conventional series motor, the series field was arranged in two parallel circuits making it possible to operate in a series connection under electronic control or in parallel connection as a conventional series motor.

Another requirement is to minimize its weight. The nominal rating of the motor is 10HP at 6000RPM with an intermittent rating of 20HP at 3000RPM. A goal of 90 lbs. was set for this motor by extrapolating from similar motors built in the past. Because of the relatively low voltage of this motor the currents are high and require a large commutator, a large brush, rigging, and heavy lead wires.

We had a choice between a 4 pole or a 6 pole configuration. For reasons of economy, we adopted the 4 pole design. To reduce weight, we provided only two interpoles which also provided space to accommodate the large number of leads. We also reduced weight by fabricating the end brackets of aluminum and the brush-holders of thin gauge brass.

We investigated the possibility of using Vanadium-Permendur for the magnetic structure but found the cost prohibitive for the small reduction in weight that could be realized.

Vanadium-Permendur contains 50% cobalt and the price of cobalt has risen from $5 a pound to $50 a pound during the last four years. It is also a material that must be imported from unreliable sources providing another reason to avoid its use.

## SUMMARY OF DESIGN

THE DESIGN IS BASED ON THE PEAK RATING OF 20HP, 3000RPM, 48 VOLTS.

Armature:

| | |
|---|---|
| Outside Diameter | $D_a$ = 5.000 in. (12.7cm) |
| Inside Diameter | $D_i$ = 1.500 in. (3.81cm) |
| Length of Stack | $L_a$ = 4.00 in. (10.16cm) |
| Number of Slots | S = 45 |
| Number of Poles | P = 4 |
| Slots per Pole Pitch | S/P= 11.25 |
| Type of Winding | Simplex Wave |
| Number of Coils | 45 |
| Turns per Coil | 1 |
| Number of Conductors | 90 |
| Conductors per Slot | 2 |
| Total Flux in the Gap | $2.69 \times 10^6$ lines |
| Distribution Constant | 0.66 |
| Magnetic Loading | Q = 1146 AN/in (451 AN/cm) |
| Flux per Pole | $4.44 \times 10^5$ lines |
| Conductors | 2 No. 10 AWG Square (2.59 x 2.59mm |
| Copper Area | .0197 in.$^2$ (.127cm$^2$) |
| Insulation | Class H |
| Current Density at 400 Amps | 10152A/in.$^2$ (1574A/cm$^2$) |
| Resistance at 25°C | .007 Ohms |
| Frequency of Armature Current | 100 Hertz |

## SUMMARY OF DESIGN-CONTINUED

| | |
|---|---|
| Amp Turns per Pole | 2250 |
| Material of Laminations | M-19, #29Ga. (.035cm) |
| Rotating Mass Inertia | 0.605 Lb.Ft.$^2$ (255Kgcm$^2$) |

Poles and Yoke:

| | |
|---|---|
| Material-Main Poles | M-19, #29Ga (.035cm) |
| Material-Interpoles | Low Carbon Steel |
| Material-Yoke (Frame) | Low Carbon Steel |
| Pole Height | 1.250 in. (3.175cm) |
| Pole Length | 4.00 in. (10.16cm) |
| Pole Width | 1.25 in. (3.175cm) |
| Interpole Dimensions | .5 x 3.5 in. (1.27 x 8.89cm) |
| Interpole Shoe | .625 in. (1.58cm) |
| Pole Arc | $60^{o}$ |
| Main Pole Air Gap | 0.071 in. (0.180cm) |
| Outside Diameter of Yoke | 8.750 in. (22.2cm) |
| Inside Diameter of Yoke | 7.640 in. (19.4cm) |
| Length of Yoke | 5.500 in. (13.97cm) |
| Magnetic Section of Pole | 4.75 in.$^2$ (30.63cm$^2$) |
| Magnetic Section of Yoke | 5.95 in.$^2$ (38.37cm$^2$) |
| Pole Leakage Constant | 1.2 |

Stationary Windings:

| | | SERIES | INTERPOLE | SHUNT |
|---|---|---|---|---|
| Size of Conductor AWG (cm) | | #7SQ (.365) | #7SQ (.365) | #24 (.051) |
| Conductor cross section ($in^2$) ($cm^2$) | | .0199 (.128) | .0199 (.128) | .000317 (.002) |
| Maximum current/section (A) | | 210 | 210 | 2.7 |
| Current density ($A/in^2$) ($A/cm^2$) | | 10552 (1636) | 10552 (1636) | 8517 (1320) |
| Turns per pole | | 8 | 17 | 400 |
| Resistance/section at 25°C | (ohm) | .01 | .007 | 40 |
| Resistance/section at 125°C | (ohm) | .014 | .01 | 56 |
| Voltage Drop | (V) | 2.94 | 2.06 | 108 |
| Watts Loss | (W) | 1180 | 825 | 292 |

Commutator and Brushes:

| | |
|---|---|
| Diameter | 4 in. (10.16cm) |
| Length of brush surface | 2.5 in. (6.35cm) |
| Number of bars | 45 |
| Bar pitch | .279 in. (.708cm) |
| Number of brushes | 8 |
| Size of brush | .375 X 1.00 in. (.952 X 2.54cm) |
| Current density (At 400 AMP) | 266A/in.$^2$ (41 A/cm$^2$) |

## SUMMARY OF COMMUTATION

| | |
|---|---|
| Bars covered by Brush | 1.342 |
| Commutating Zone on Armature Surface | 0.73 in. (1.85cm) |
| Width of Neutral Zone | 1.335 in. (3.39cm) |
| Width of Interpole Shoe | 0.625 in. (1.59cm) |
| Gap of Interpole | .045 in. (114cm) |
| Commutating Zone in % of Neutral | 54% |
| Reactance Volts at 400A | 0.7 volts |
| Interpole Gap Density | 12732 L/in.$^2$ (1974 Gausses) |
| Amp. Turns for Gap Density | 148 |
| Armature Reaction (At 400 AMP) | 2250 AT/Pole |
| Total Amp Turns Required (Approx. 125%) | 3400 AT/Pole |
| Turns per Int. Pole (2 Par. Circ.) | 17 |

LOSS PROFILE AT OVERLOAD.

| Resistance drop at overload (at 420 AMPS and 125°C) | | | | (25°C) |
|---|---|---|---|---|
| Armature IR | .008 X 1.4 X 420 | = | 4.70 V | 3.36 V |
| Series Field IR | .005 X 1.4 X 420 | = | 2.94 V | 2.10 V |
| Interpole IR | .0035 X 1.4 X 420 | = | 2.06 V | 1.47 V |
| Brush Drop (Copper Graphite) | | = | 1.00 V | .71 V |
| | | | 10.70 V | 7.64 V |

| Losses (at 20HP, 3000 RPM) | | |
|---|---|---|
| Copper and Brush Contact<br>10.70 Volts X 420 AMPS | 4495 Watts | 3209 W |
| Brush Friction | 95 Watts | 95 W |
| Iron Losses | 160 Watts | 160 W |
| Friction + Windage | 90 Watts | 90 W |
| Stray Load | 400 Watts | 400 W |
| | 5240 Watts | 3954 W |

$$\text{Efficiency} = \frac{14920}{14920 + 5240} = .74 \text{ (at } 125^{\circ}\text{C)}$$

$$\text{Efficiency} = \frac{14920}{14920 + 3954} = .79 \text{ (at } 25^{\circ}\text{C)}$$

Torque at 3000 RPM

$$T_D = \frac{7.04 \times 2.69 \times 10^6 \times 90 \times 420 \times .66}{2 \times 60 \times 10^8} = 39.4 \text{ LBS. Ft.}$$

$$= 53.4 \text{ N-m)}$$

Required Torque = 35 LBS Ft. (47.46 N-m)

LOSS PROFILE AT RATED LOAD.

| Full Load Resistance Drop (at 183 AMPS and 125°C) | | (25°C) |
|---|---|---|
| Armature IR | 2.04 V | 1.46 V |
| Series IR | 1.28 V | .91 V |
| Interpole IR | 0.89 V | .64 V |
| Brush Drop (Copper Graphite) TOTAL | 0.50 V | .50 V |
| TOTAL | 4.71 V | 3.51 V |

| Full Load Losses (at 183 AMPS, 6000RPM) | | |
|---|---|---|
| Copper and Brush Contact 4.71 X 183 | 862 Watts | 642 W |
| Brush Friction | 95 Watts | 95 W |
| Iron Losses | 50 Watts | 50 W |
| Windage + Friction | 200 Watts | 200 W |
| Stray Load | 100 Watts | 100 W |
| | 1307 Watts | 1087 W |

$$\text{Efficiency} = \frac{7460}{7460 + 1307} = .85 \text{ (at } 125^{\circ}\text{C)}$$

$$\text{Efficiency} = \frac{7460}{7460 + 1087} = .87 \text{ (at } 25^{\circ}\text{C)}$$

Torque at 6000 RPM

$$T_d = \frac{7.04 \times 1.47 \times 10^6 \times 90 \times 183 \times .66}{2 \times 60 \times 10^8} = 9.37 \text{ LBS Ft.}$$

$$= 12.71 \text{ N-m)}$$

Required Torque = 8.75 LBS. Ft.

= (11.87 N-m)

## MAGNETIC CIRCUIT AT 3000RPM, 20HP

| AREA | DENSITY | | LENGTH | | AT/IN | OERSTED | AT/POLE |
|---|---|---|---|---|---|---|---|
| | LINES/IN$^2$ | GAUSSES | IN | CM | | | |
| GAP | 42500 | 6589 | .071 | .180 | ---- | ----- | 1131 |
| TEETH | 102000 | 15814 | .600 | 1.524 | 85 | 42 | 51 |
| ARM.YOKE | 80000 | 12403 | 1.500 | 3.810 | 10 | 4.95 | 15 |
| POLE | 106000 | 16434 | 1.250 | 3.175 | 125 | 61.84 | 159 |
| FRAME | 90000 | 13953 | 3.22 | 8.179 | 40 | 19.79 | 129 |

TOTAL = 1485

BECAUSE OF ARMATURE CROSS MAGNETIZATION THE ACTUAL TOTAL AT/POLE ARE 1600.

## MAGNETIC CIRCUIT AT 6000RPM, 10HP

| AREA | DENSITY LINES/$in^2$ | DENSITY GAUSSES | LENGTH IN | LENGTH CM | AT/IN | OERSTED | AT/POLE |
|---|---|---|---|---|---|---|---|
| GAP | 23200 | 3596 | .071 | .180 | ---- | ----- | 609 |
| TEETH | 55300 | 8573 | .600 | 1.52 | 3.5 | 1.73 | 2.1 |
| ARM.YOKE | 26000 | 4031 | 1.50 | 3.81 | 1.5 | 0.74 | 2.3 |
| POLE | 57600 | 8930 | 1.25 | 3.18 | 4 | 1.98 | 5.0 |
| FRAME | 47200 | 7317 | 3.22 | 8.18 | 10 | 4.95 | 32.2 |
| | | | | | | TOTAL = | 650.6 |

BECAUSE OF CROSS MAGNETIZATION THE ACTUAL AT/POLE ARE 732.

DISCUSSION.

The purchase description for this motor specifies two points for the Speed - Torque Characteristic. 10HP at 6000RPM and 20HP at 3000RPM. By careful choice of saturation levels, air-gap and series field turns we were able to accommodate both points at the same voltage level. This relegates the shunt field to balancing the speed of the two motors, to angle control and intermittent regenerative braking. There is no need any more to maintain a large shunt field on the low speed end in order to reach top speed by weakening this field as was envisioned in the Interim Report.

As mentioned previously we encountered some difficulty with commutation. In order to save weight, this motor has only two commutating poles. Therefore, the commutating pole flux has to return through the main pole. But the main pole becomes highly saturated at overloads and cannot accommodate the additional interpole flux. For proper operation of the interpoles it is necessary to maintain linearity between flux and current which cannot be accomplished while the main flux is subject to large fluxtuations. Therefore, we had to compromise in the calibration of the interpoles in order to achieve a tolerable degree of commutation.

As a further consequence of our difficulties with commutation we could not achieve the efficiency during overload that was predicted in the interim report. This is due to parasitic torques in the conductors undergoing commutation and is buried in the loss profile under the heading of Stray Load Losses. Nevertheless, the efficiency is still as good as on machines weighing much more.

In order to further improve the efficiency of the motor under solid state control, one could laminate the entire field structure of the motor. This may produce a measurable reduction in iron losses. The additional cost of the laminated motor would have to be justified by the possible energy savings over the life of the motor. This is a subject that is beyond the scope of this present study.

The airflow was maintained at 200 CFM during our test program. The pressure drop at this flow rate is 1.0 in. of water.

## ANALYSIS OF COMPARABLE WEIGHT AND COST OF A SINGLE MOTOR RATED 20HP VS. TWO 10HP MOTORS.

We assume in this analysis that the 10HP motors are 48 Volt motors operating in a series connection and that the 20HP motor is rated at 96 Volt. This keeps the current in both ratings the same and permits us to use the same size commutators, brush-riggings, and cables. Based on the above assumptions the 10HP motor will weigh 95 LBS. and the 20HP motor will weigh 163 LBS.

A Cost Breakdown for these motors based on 1979 Dollars follows:

| QUANTITY | 10HP | 20HP |
|---|---|---|
| 100 | \$ 1250.00 | \$ 1800.00 |
| 1000 | \$ 1060.00 | \$ 1530.00 |
| 10000 | \$ 875.00 | \$ 1260.00 |

Weight of Parts:

| | | |
|---|---|---|
| Bearing Bracket Ext. End Aluminum | 3.69 lbs. | (1.67Kg) |
| Bearing Bracket Comm. End Aluminum | 5.57 lbs. | (2.52Kg) |
| Frame Ring Steel | 21.72 lbs. | (9.85Kg) |
| 4 Main Poles | 8.57 lbs. | (3.89Kg) |
| 2 Int. Poles | 1.25 lbs. | (0.57Kg) |
| M.P. Coils | 3.7 lbs. | (1.68Kg) |
| I.P. Coils | 2.75 lbs. | (1.24Kg) |
| Armature Coils | 5.00 lbs. | (2.27Kg) |
| Armature Laminations | 16.10 lbs. | (7.30Kg) |
| Commutator | 9.35 lbs. | (4.24Kg) |
| Cables | 2.00 lbs. | (0.91Kg) |
| Shaft | 6.31 lbs. | (2.86Kg) |
| 2 Bearings | 1.00 lb. | (0.45Kg) |
| Brush Holders | 1.12 lbs. | (0.51Kg) |
| Brushes | .45 lb. | (0.20Kg) |
| Rocker Ring | .24 lb. | (0.11Kg) |
| Cover - Ext. End | .91 lb. | (0.41Kg) |
| Bearing Inserts | .36 lb. | (0.16Kg) |
| Cover Commutator End | 3.00 lbs. | (1.36Kg) |
| Hardware | 1.91 lbs. | (0.86Kg) |
| TOTAL | 95 lbs. | 43 Kg |

ALTERNATIVE CONCEPT MOTORS .

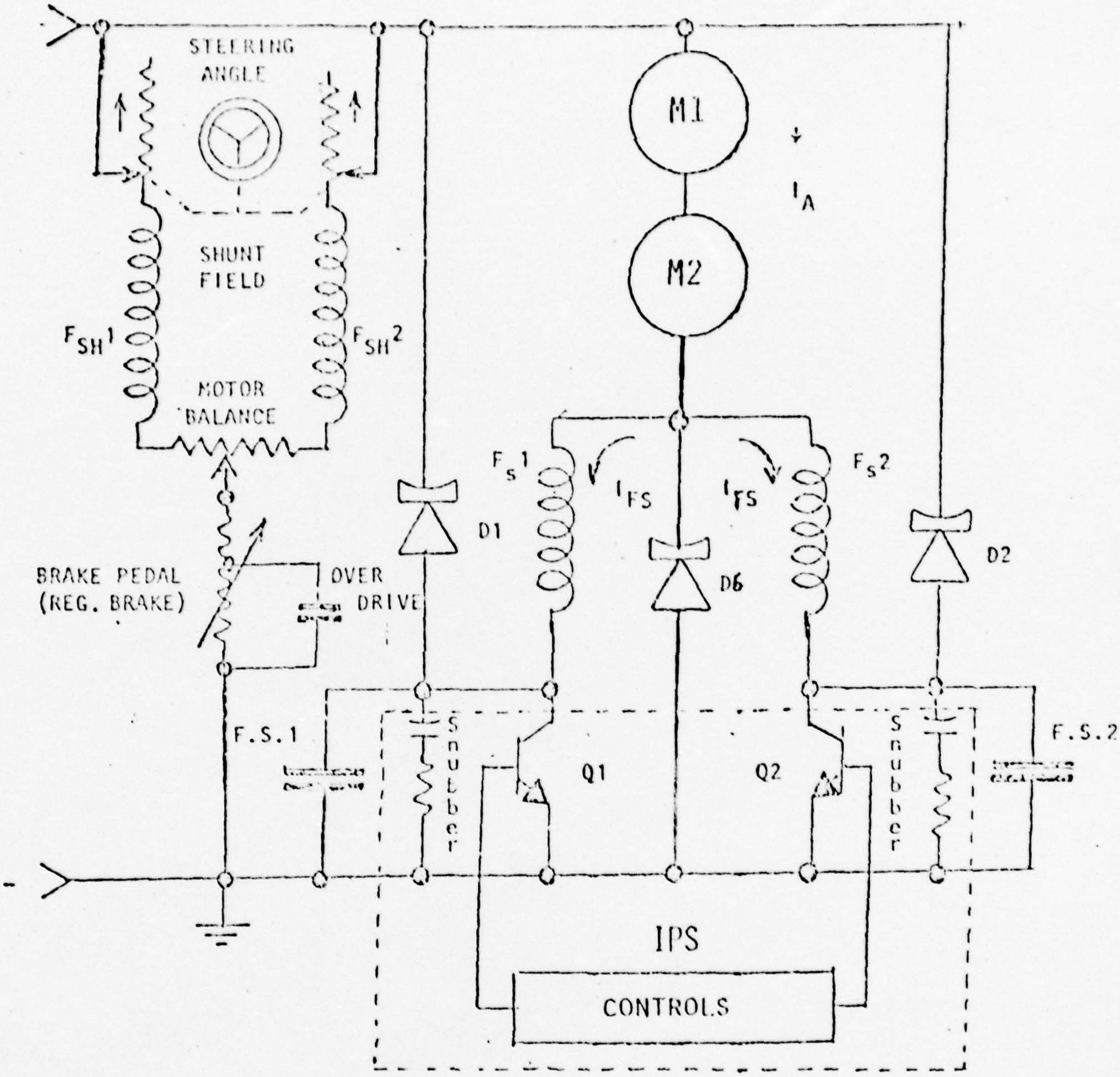
In discussions with representative of MERADCOM it was agreed that endurance testing and environmental testing as prescribed by Par. 4.4 and Par. 4.5 should be cancelled and that instead two more motors be built.

The original motors had radial brushes in order to insure complete by-directional capability. A radial brush is not very stable and under certain conditions, especially under very high speed, may cause chatter with simultaneous arcing.

Brushes in trailing configuration or reaction type brushes are much more immune to chatter but have one disadvantage; they are unidirectional.

In view of the fact that propulsion motors operate in one direction most of the time, we will take advantage of this characteristic and build these motors with trailing type brushholders.

The original motors had only 2 interpoles which caused some difficulties with the interpole flux due to saturation of the main poles. Therefore it was decided to incorporate 4 interpoles in the new motors.




F.S. = FULL SPEED CONTACTOR

FIGURE 1

Patent Applied
USAMERADCOM, Elec Power Lal
Electrical Equipment Divisi
Fort Belvoir, Virginia 220

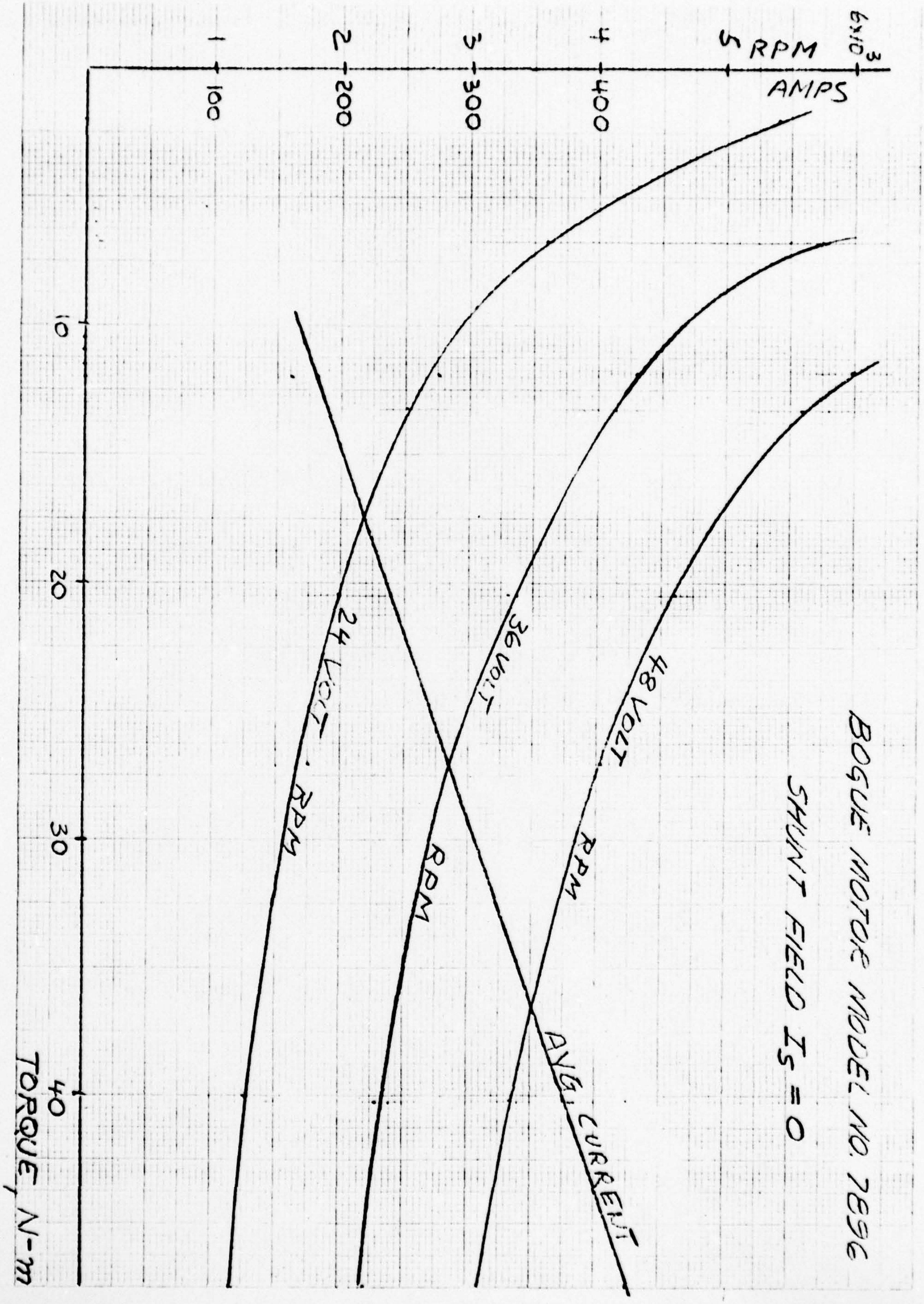

BOGUE MOTOR MODEL NO. 7896
SHUNT FIELD $I_S = 0$
RPM
AMPS
1
2
3
4
5
$6 \times 10^3$
100
200
300
400
10
20
30
40
48 VOLT RPM
36 VOLT RPM
24 VOLT RPM
AVG. CURRENT
TORQUE, N-m

FIG. 2

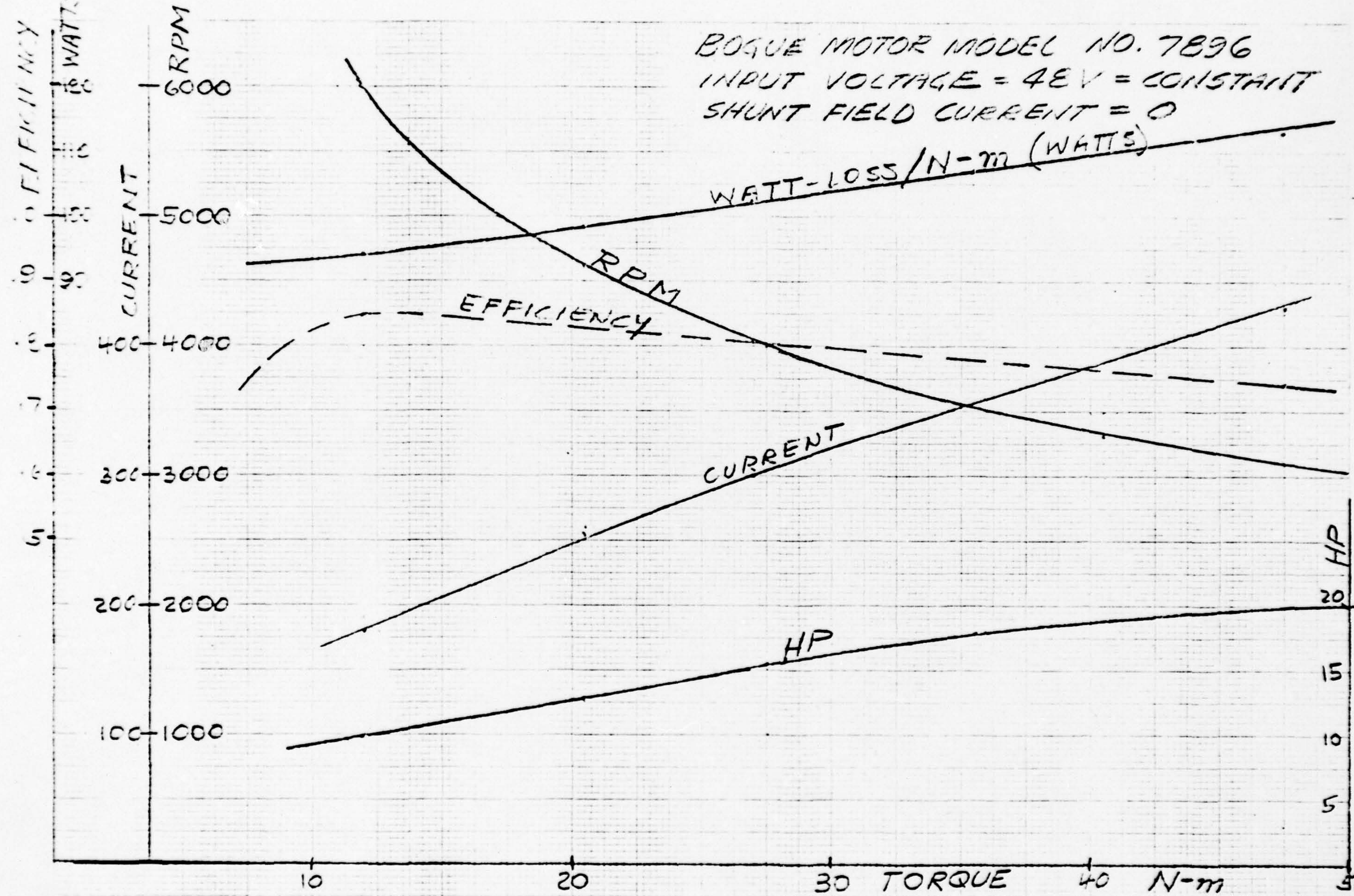
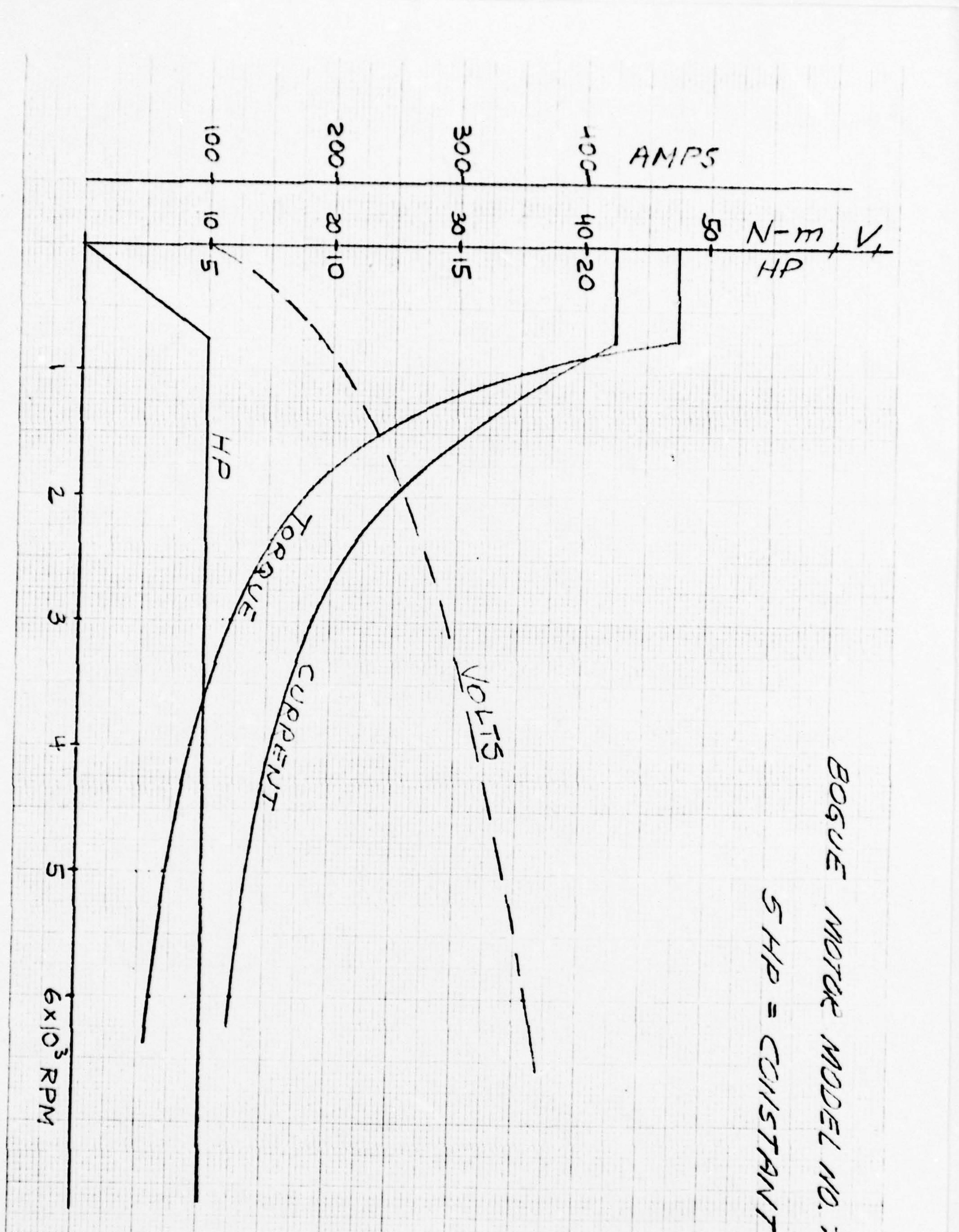

BOGUE MOTOR MODEL NO. 7896
INPUT VOLTAGE = 48 V = CONSTANT
SHUNT FIELD CURRENT = 0
WATT-LOSS/N-m (WATTS)
RPM
EFFICIENCY
CURRENT
HP
EFFICIENCY
WATTS
CURRENT
RPM
TORQUE
N-m
HP

FIG. 3



BOGUE MOTOR MODEL NO. 7896
5 HP = CONSTANT
AMPS
100
200
300
400
N-m, V,
HP
10
20
30
40
50
5
10
15
20
1
2
3
4
5
6x10$^3$ RPM
HP
TORQUE
CURRENT
VOLTS


FIG. 4

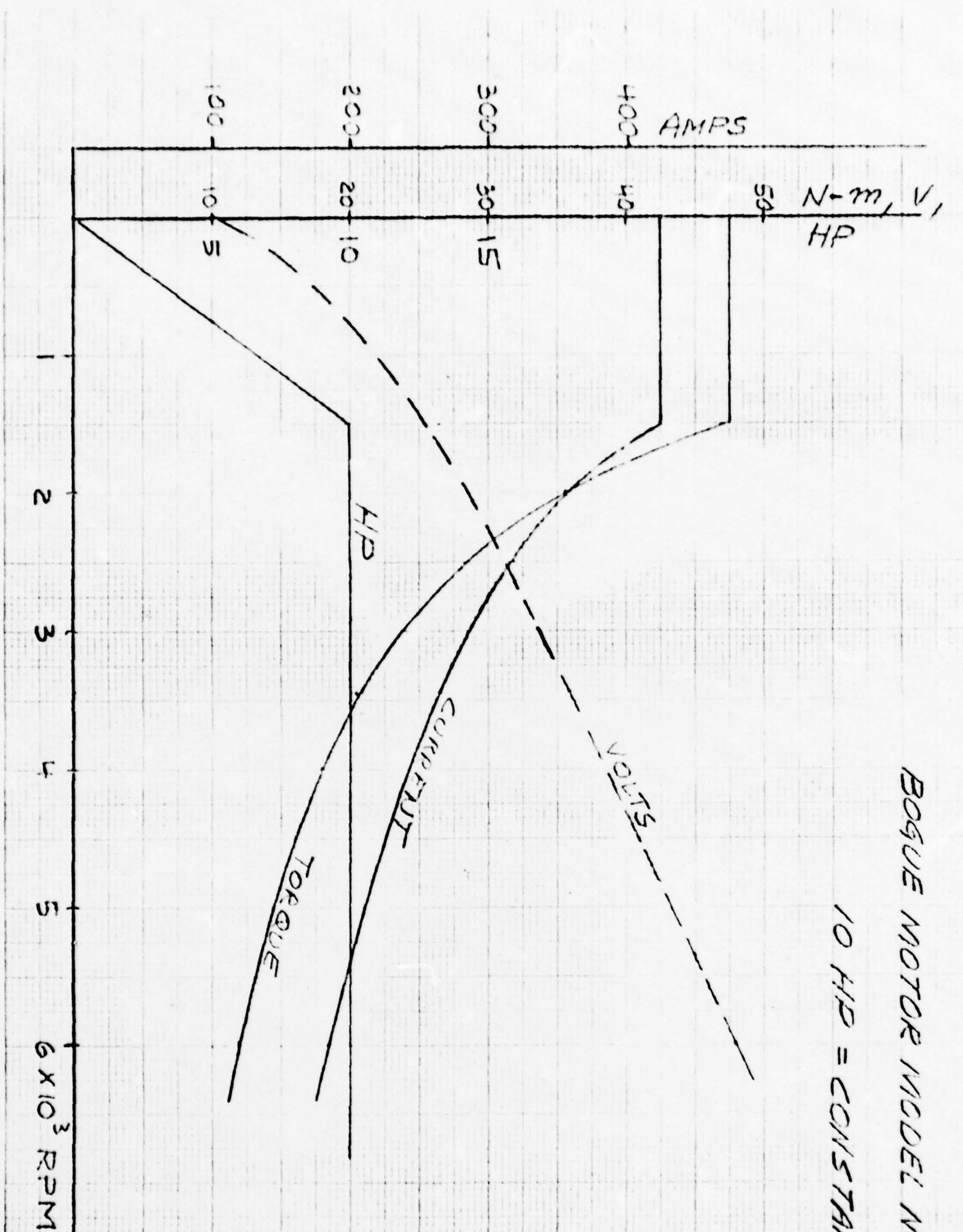

BOGUE MOTOR MODEL NO. 7856
10 HP = CONSTANT
AMPS
100
200
300
400
N-m, V,
HP
10
20
30
40
50
5
10
15
1
2
3
4
5
6 x 10^3 RPM
HP
CURRENT
VOLTS
TORQUE

FIG. 5

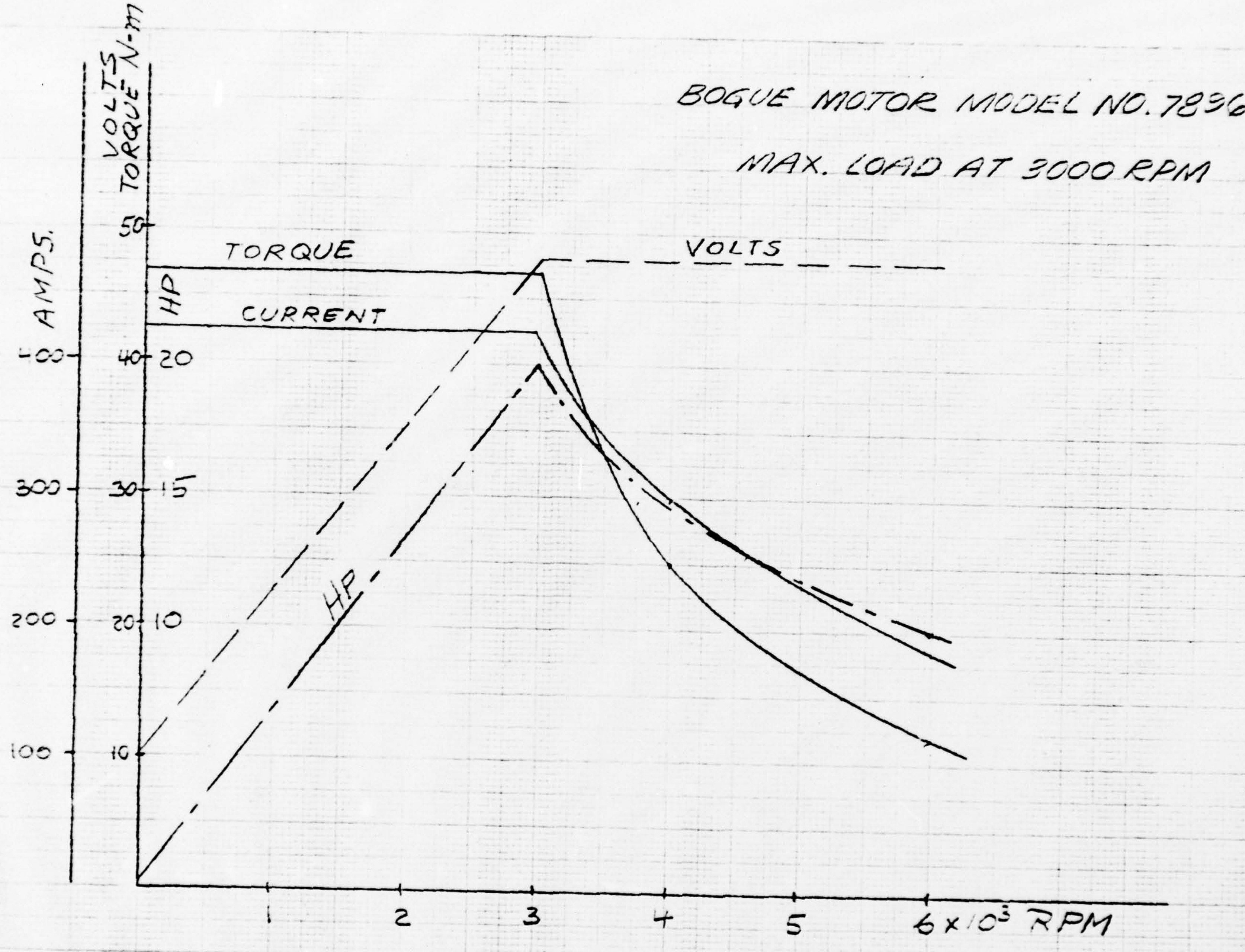
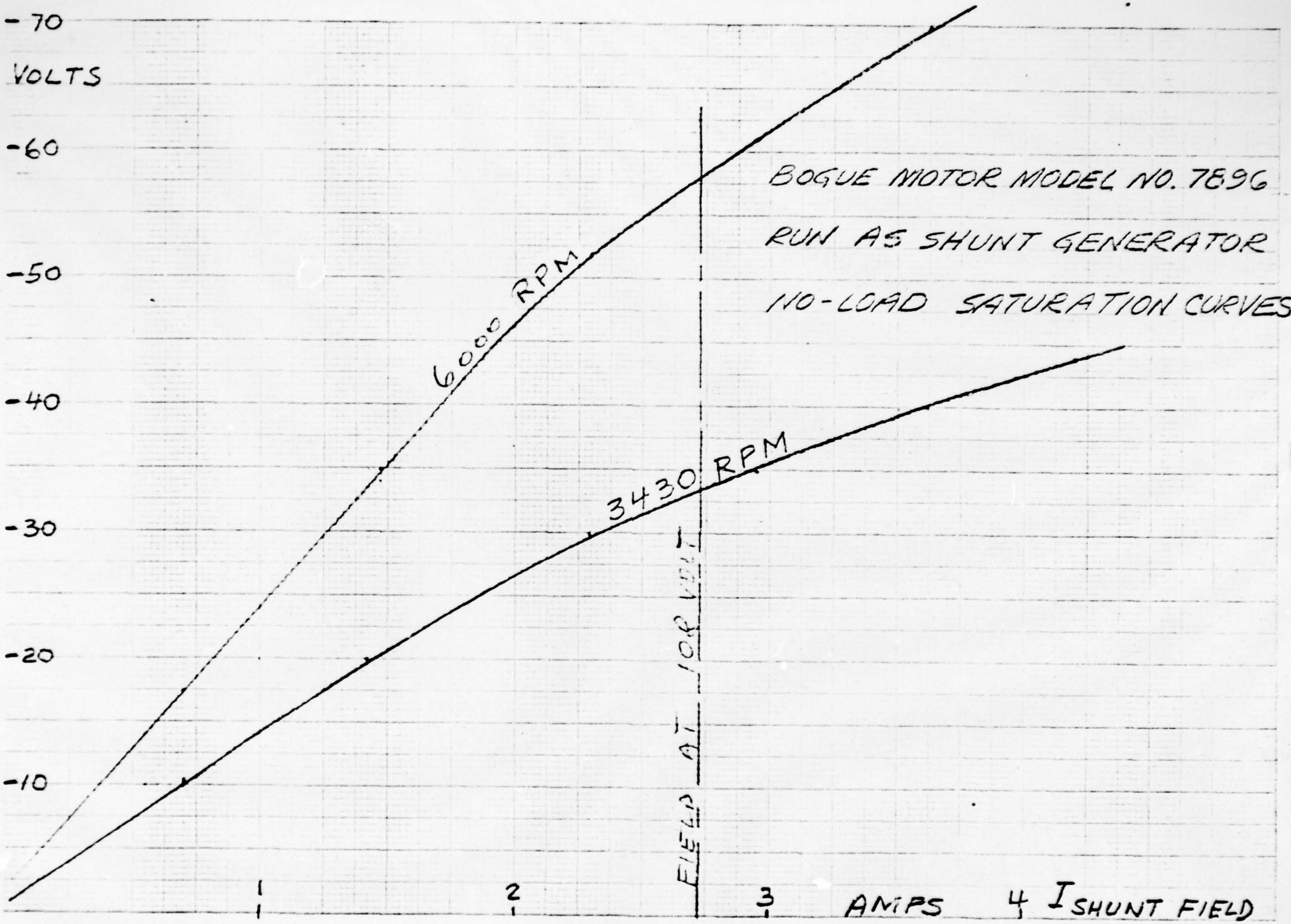

BOGUE MOTOR MODEL NO. 7896
MAX. LOAD AT 3000 RPM
AMPS.
VOLTS
TORQUE N-m
HP
TORQUE
CURRENT
VOLTS
HP
100
200
300
400
10
20
30
40
50
10
15
20
1
2
3
4
5
6 x 10³ RPM

FIG. 6



-70
VOLTS
-60
-50
-40
-30
-20
-10
1
2
3
AMPS
4 $I_{SHUNT\ FIELD}$
6000 RPM
3430 RPM
FIELD AT 10R VOLT
BOGUE MOTOR MODEL NO. 7896
RUN AS SHUNT GENERATOR
NO-LOAD SATURATION CURVES


FIG. 7

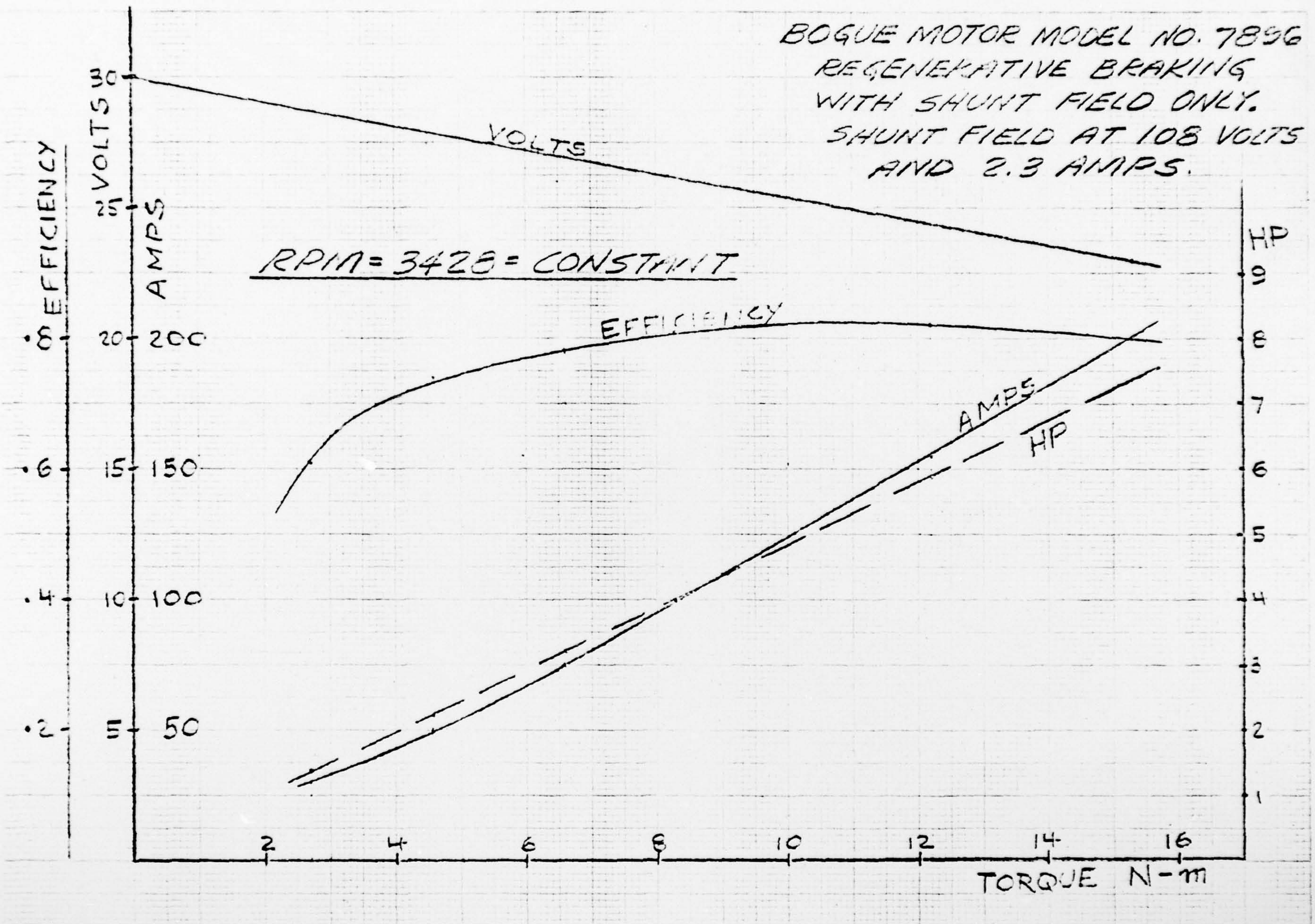
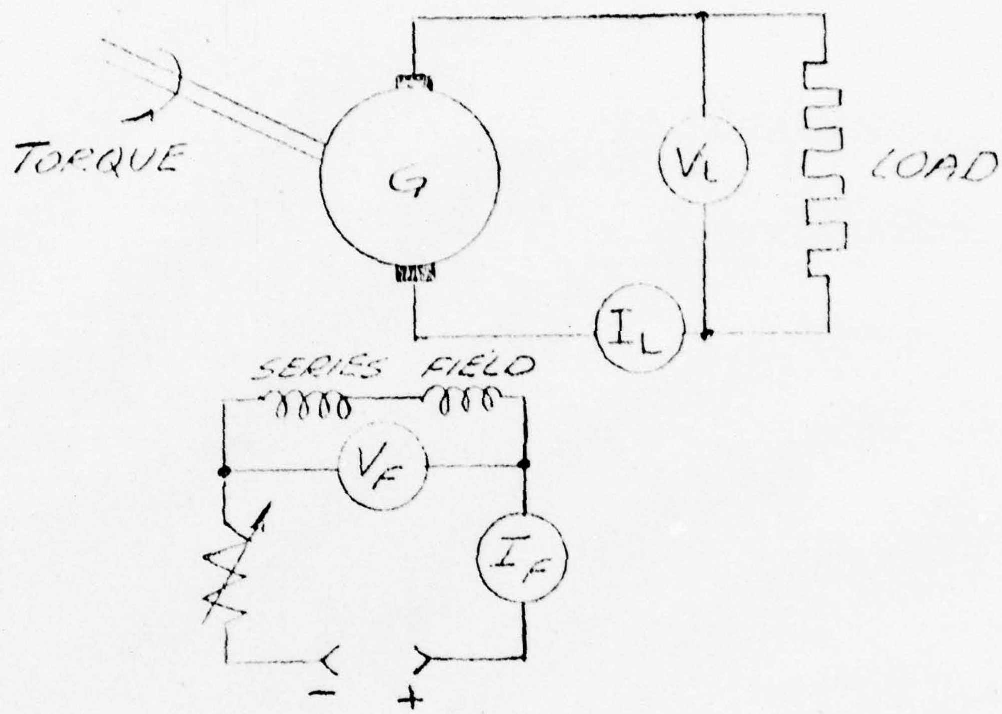

BOGUE MOTOR MODEL NO. 7896
REGENERATIVE BRAKING
WITH SHUNT FIELD ONLY.
SHUNT FIELD AT 108 VOLTS
AND 2.3 AMPS.
RPM = 3428 = CONSTANT
EFFICIENCY
VOLTS
AMPS
HP
.2
.4
.6
.8
5
10
15
20
25
30
50
100
150
200
1
2
3
4
5
6
7
8
9
TORQUE N-m
2
4
6
8
10
12
14
16

FIG. 8

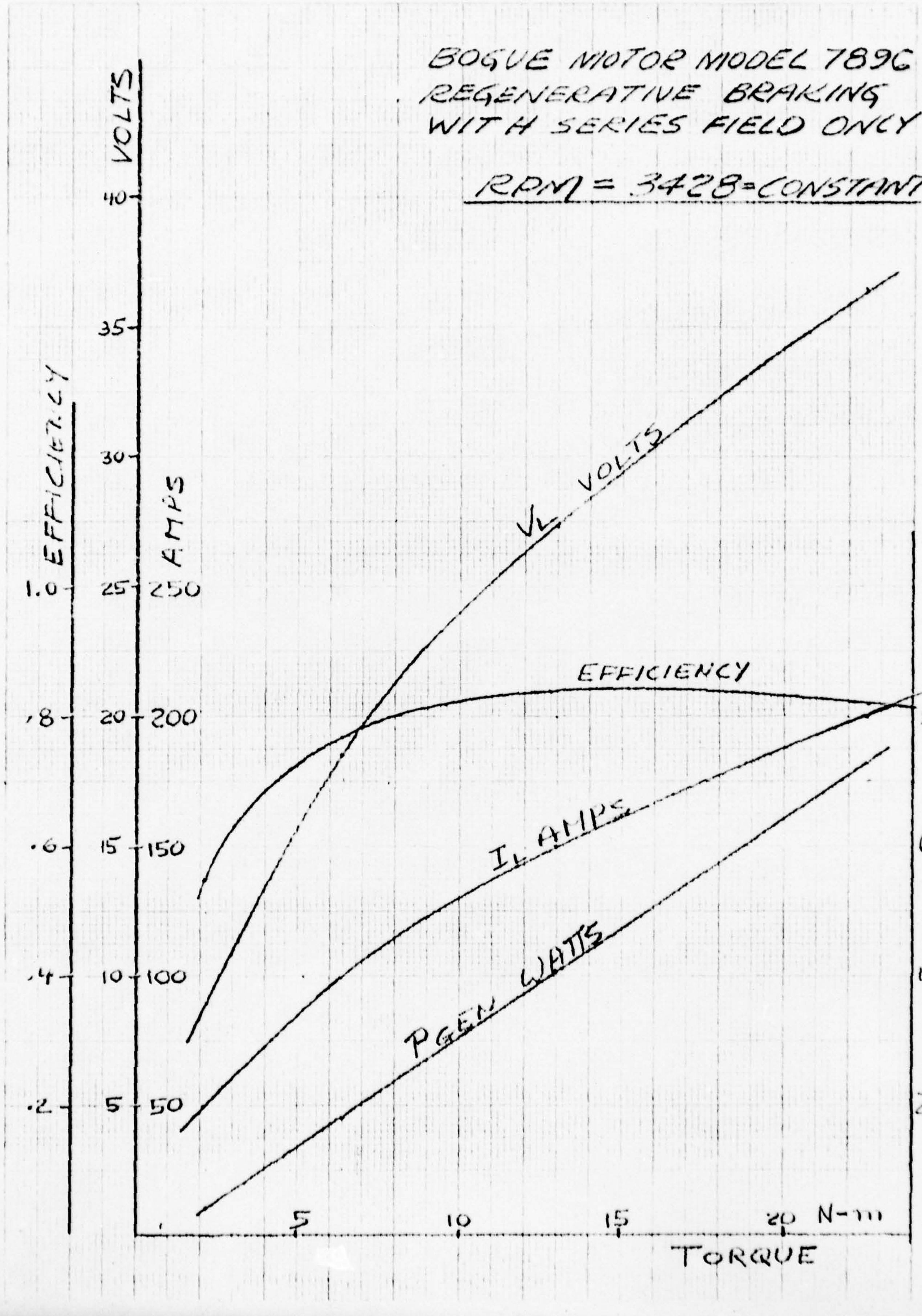
REGENERATIVE BRAKING WITH SERIES FIELD ONLY




RPM = 3428

| $I_L$ | $V_L$ | $I_F$ | $V_F$ | TORQUE | $P_{GEN}$ | $P_{INPUT}$ | EFFICIENC |
|---|---|---|---|---|---|---|---|
| A | V | A | V | N-m | $I_L V_L$ | $(359 \times T_Q) + V_F I_F$ | $P_G / P_{INP}$ |
| | | | | 0.81 | 0 | 290 | 0 |
| 50 | 8.8 | 31 | .62 | 2.17 | 440 | 798 | .55 |
| 100 | 18.3 | 70 | 1.40 | 6.37 | 1830 | 2385 | .77 |
| 150 | 27.4 | 118 | 2.36 | 12.88 | 4110 | 4902 | .84 |
| 200 | 36.5 | 196 | 3.92 | 22.64 | 7300 | 8896 | .82 |
| | | | | | | | |

FIG. 9



BOGUE MOTOR MODEL 789C
REGENERATIVE BRAKING
WITH SERIES FIELD ONLY
RPM = 3428 = CONSTANT
VOLTS
EFFICIENCY
AMPS
WATTS
$V_L$ VOLTS
EFFICIENCY
$I_L$ AMPS
PGEN WATTS
TORQUE
N-m
40
35
30
25
20
15
10
5
1.0
.8
.6
.4
.2
250
200
150
100
50
2000
4000
6000
5
10
15
20


FIG. 10

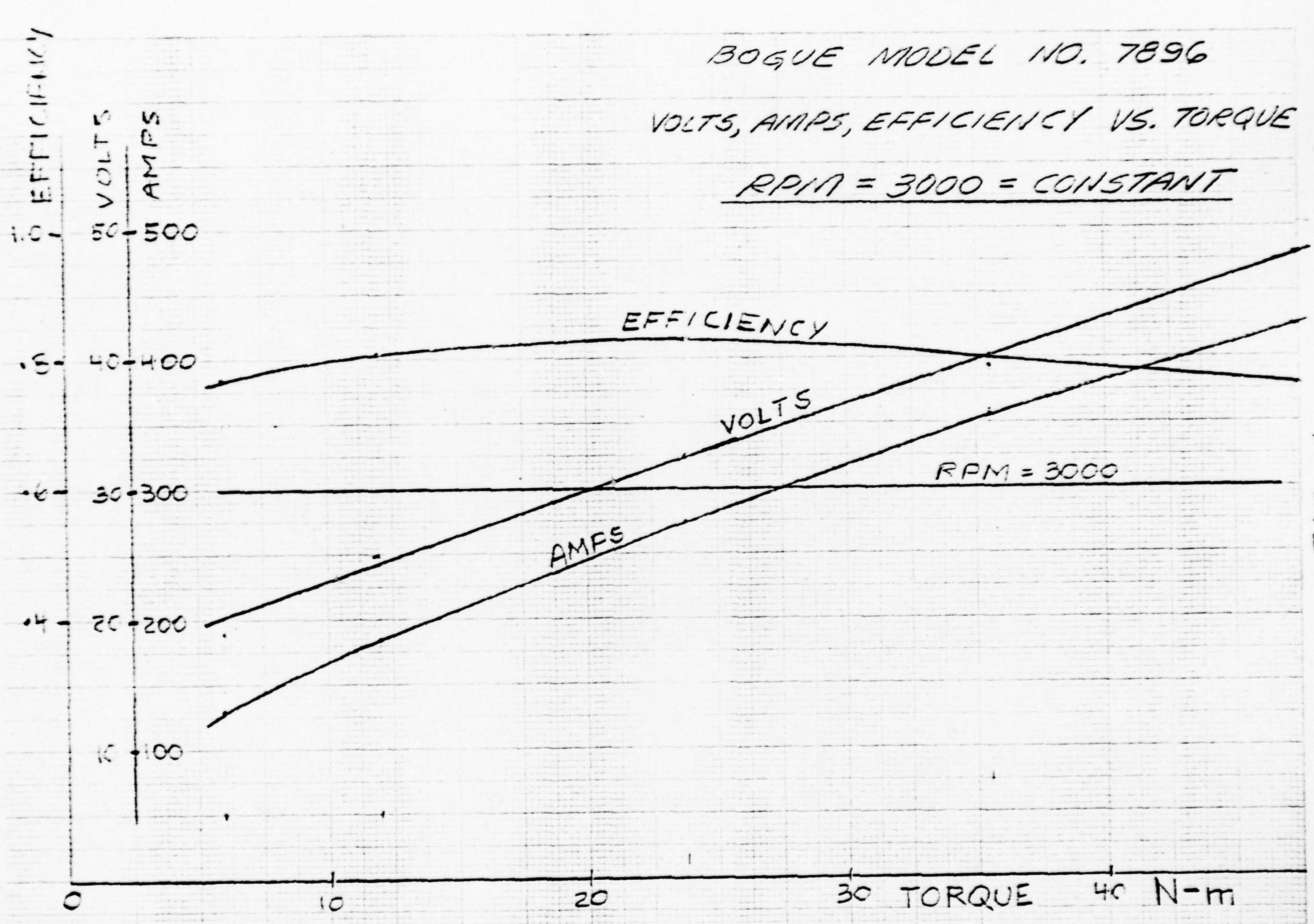

BOGUE MODEL NO. 7896
VOLTS, AMPS, EFFICIENCY VS. TORQUE
RPM = 3000 = CONSTANT
EFFICIENCY
VOLTS
AMPS
1.0
.8
.6
.4
50
40
30
20
10
500
400
300
200
100
EFFICIENCY
VOLTS
RPM = 3000
AMPS
0
10
20
30
40
TORQUE
N-m

FIG. 11

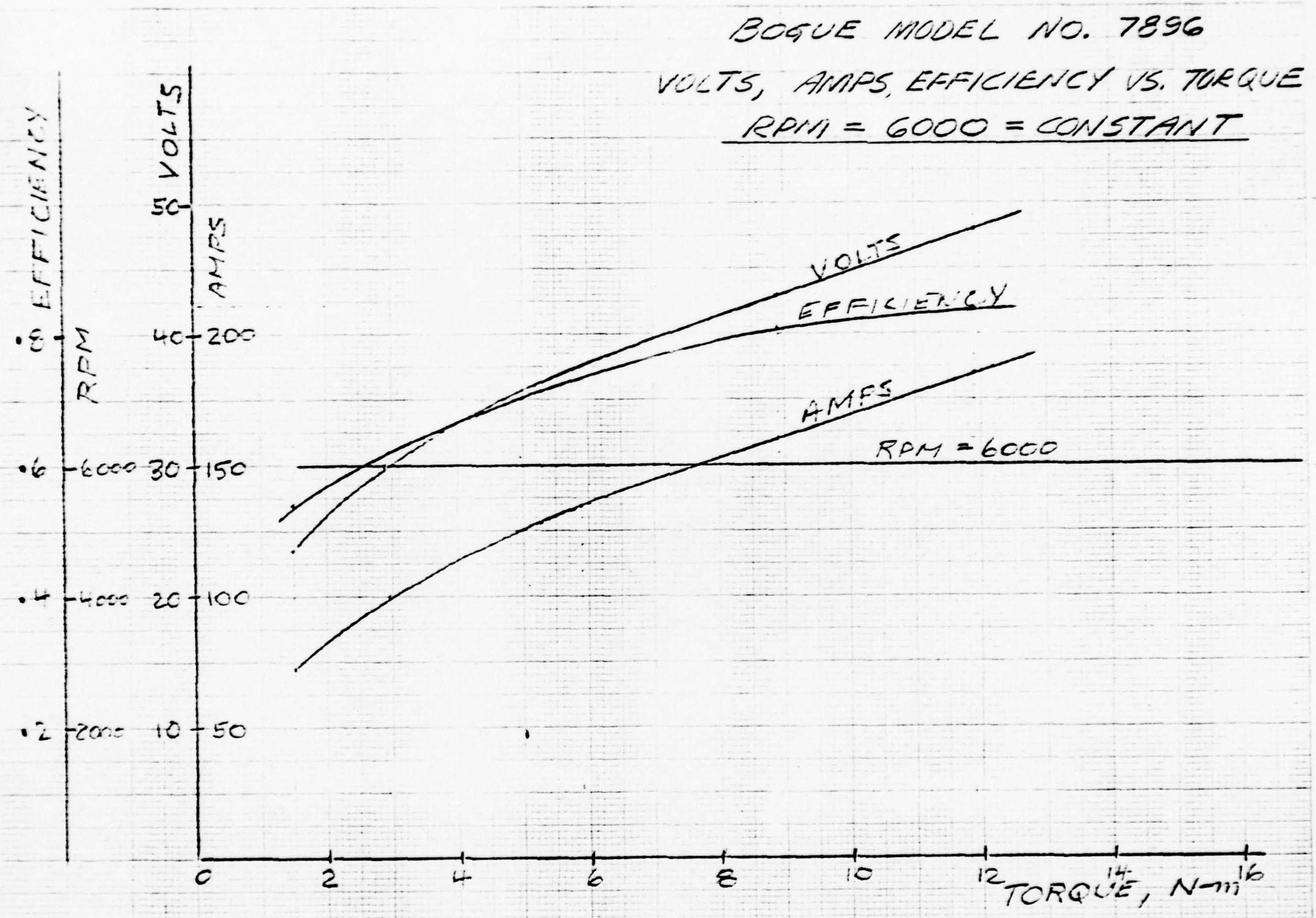
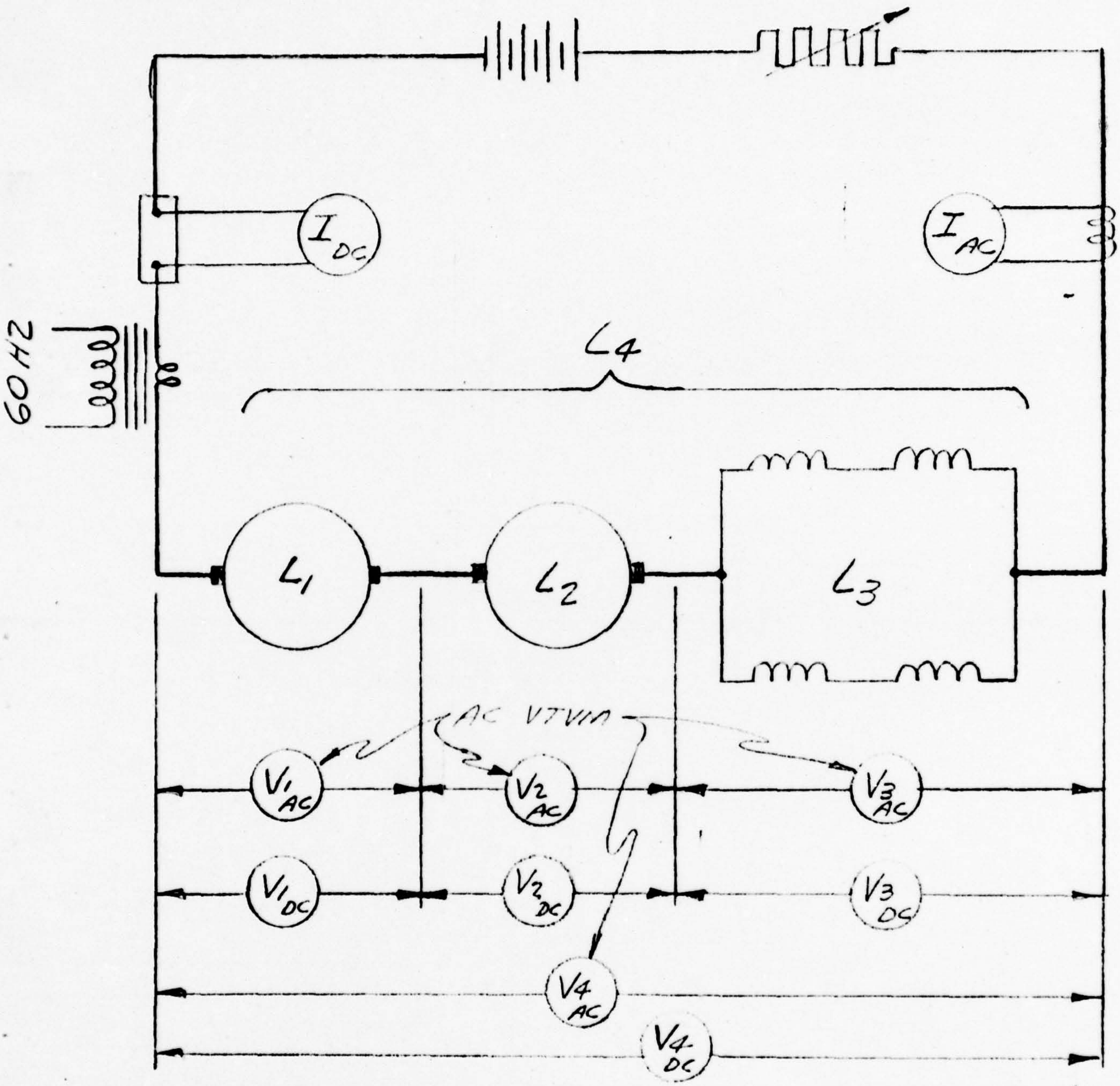

BOGUE MODEL NO. 7896
VOLTS, AMPS, EFFICIENCY VS. TORQUE
RPM = 6000 = CONSTANT
EFFICIENCY
RPM
VOLTS
AMPS
.2
.4
.6
.8
2000
4000
6000
10
20
30
40
50
50
100
150
200
0
2
4
6
8
10
12
14
16
TORQUE, N-m
VOLTS
EFFICIENCY
AMPS
RPM = 6000

FIG 12

## COMPUTATION OF INDUCTANCES



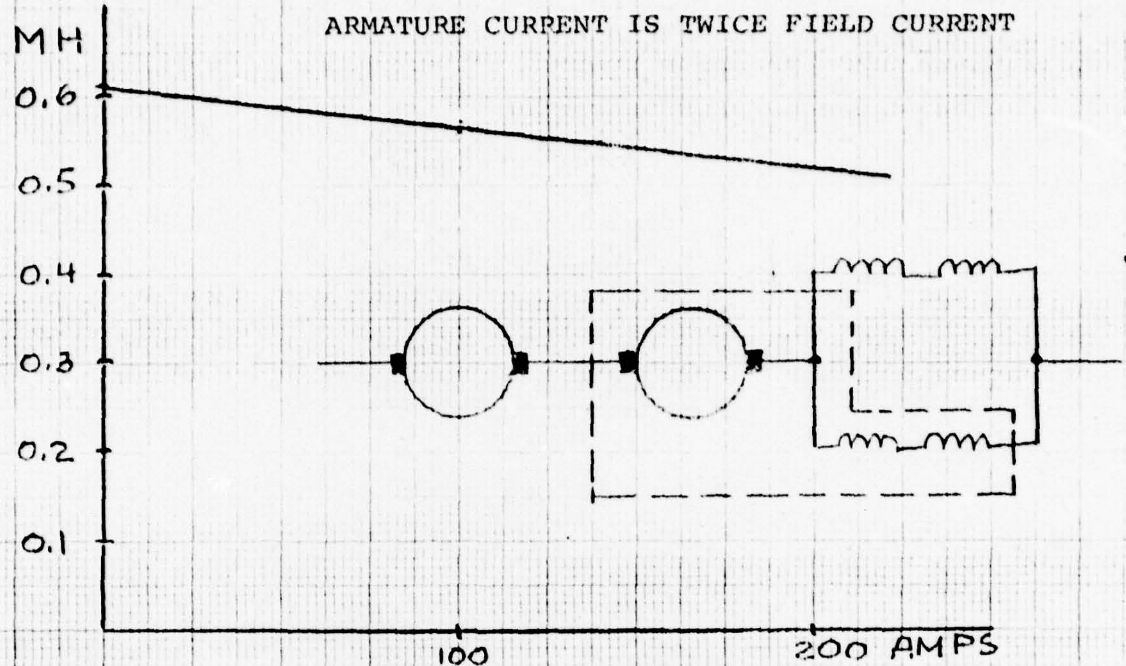

| $I_{AC}$ | $I_{DC}$ | $V_1$ | | $V_2$ | | $V_3$ | | $V_4$ | | $L_1$ | $L_2$ | $L_3$ | $L_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AC | DC | AC | DC | AC | DC | AC | DC | MH | MH | MH | MH |
| 17.5 | 0 | 1.15 | 0 | 1.15 | 0 | 1.5 | 0 | 3.8 | 0 | .17 | .17 | .22 | .55 |
| 17.5 | 100 | 1.05 | 1.80 | 1.05 | 1.80 | 1.4 | 1.05 | 3.5 | 4.65 | .15 | .15 | .21 | .51 |
| 17.5 | 200 | 1.00 | 3.10 | 1.00 | 3.10 | 1.3 | 2.10 | 3.3 | 8.30 | .145 | .145 | .19 | .48 |
| 17.5 | 400 | 0.95 | 5.85 | 0.95 | 5.85 | 1.2 | 4.20 | 3.1 | 15.90 | .14 | .14 | .18 | .46 |

FIG. 13

BOGUE MODEL NO. 7896

MOTOR INDUCTANCE VS. FIELD CURRENT

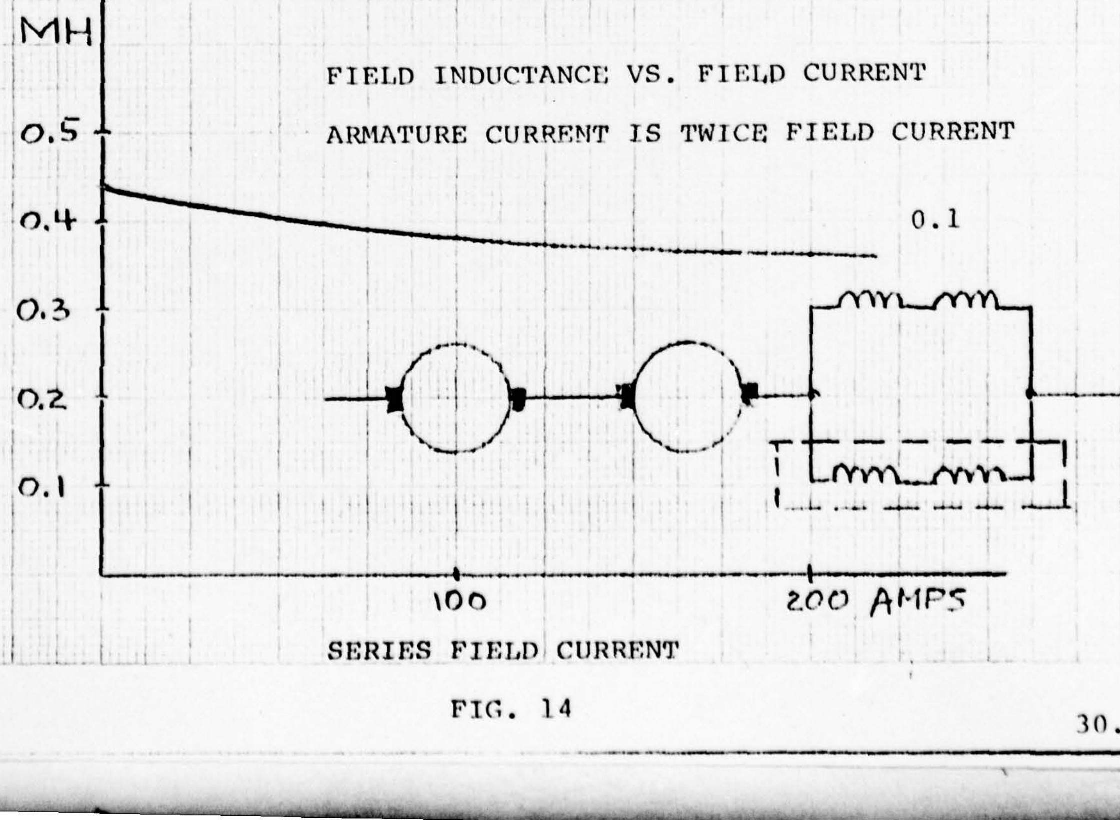
ARMATURE CURRENT IS TWICE FIELD CURRENT




SERIES FIELD CURRENT

FIELD INDUCTANCE VS. FIELD CURRENT

ARMATURE CURRENT IS TWICE FIELD CURRENT




SERIES FIELD CURRENT

FIG. 14

**BOGUE ELECTRIC MFG. CO.**
**QUALITY CONTROL**
**TEST DATA**

| Contract or Order No. | Job or Model No. | Serial No. | Type of Test | Date | Dept. | Page ___ of ___ |
|---|---|---|---|---|---|---|
| | 7896 | | HEAT RUN | 6/6/79 | 15 | |

Description of Equipment: 10 HP, 6000 RPM
48 V, 183 AMPS.

| Spec. | Paragraph | Test No. | Spec. | Paragraph | Test No. |
|---|---|---|---|---|---|
| 4.8 | Temperature Rise | | | | |
| | Air Flow | | | | |

Applicable specification

| | | | |
|---|---|---|---|
| A | QC-7896/I | D | |
| B | | E | |
| C | | F | |
| | | G | |

| | $E_{in}$ | $I_{in}$ | RPM | Torque | | THERMOCOUPLES: °C 1 | 2 | 3 | 4 | 5 | | Time | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | A | | N-m | | Main Pole | Main Pole | Inter Pole | Brush | Ambient | | | |
| | 48 | 183 | 6100 | 11.86 | | 41 | 42 | 40 | 61 | 25 | | 9:40 | |
| | 48 | 183 | 6100 | 11.86 | | 55 | 58 | 49 | 63 | 26 | | 9:50 | |
| | 48 | 183 | 6100 | 11.86 | | 58 | 62 | 52 | 65 | 26 | | 10:00 | |
| | 48 | 183 | 6100 | 11.86 | | 59 | 63 | 52 | 68 | 26 | | 10:15 | |
| | 48 | 183 | 6100 | 11.86 | | 60 | 63 | 54 | 67 | 27 | | 10:25 | |
| | 48 | 183 | 6100 | 11.86 | | 61 | 63 | 54 | 67 | 27 | | 10:35 | |
| | 48 | 183 | 6100 | 11.86 | | 61 | 63 | 54 | 67 | 27 | | 10:45 | |
| | 48 | 183 | 6100 | 11.86 | | 61 | 63 | 54 | 67 | 27 | | 10:55 | |

AIR FLOW: 200 CFM

STATIC PRESSURE DROP = 1 inch $H_2O$

FIG. 15

Tester:

Government Inspector:

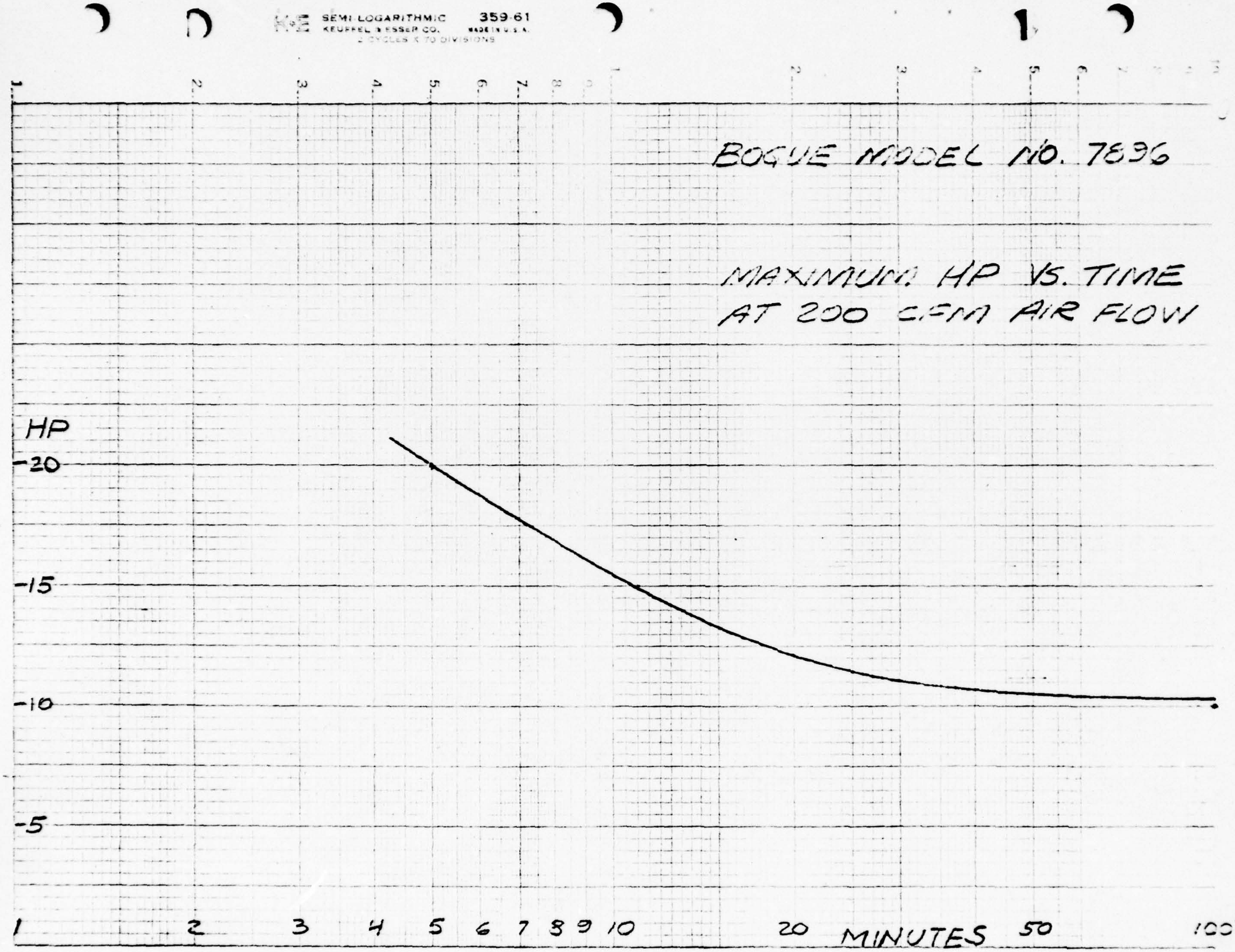

SEMI-LOGARITHMIC 359-61
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 CYCLES X 70 DIVISIONS
BOGUE MODEL NO. 7896
MAXIMUM HP VS. TIME
AT 200 CFM AIR FLOW
HP
20
15
10
5
1
2
3
4
5
6
7
8
9
10
20
MINUTES
50
100

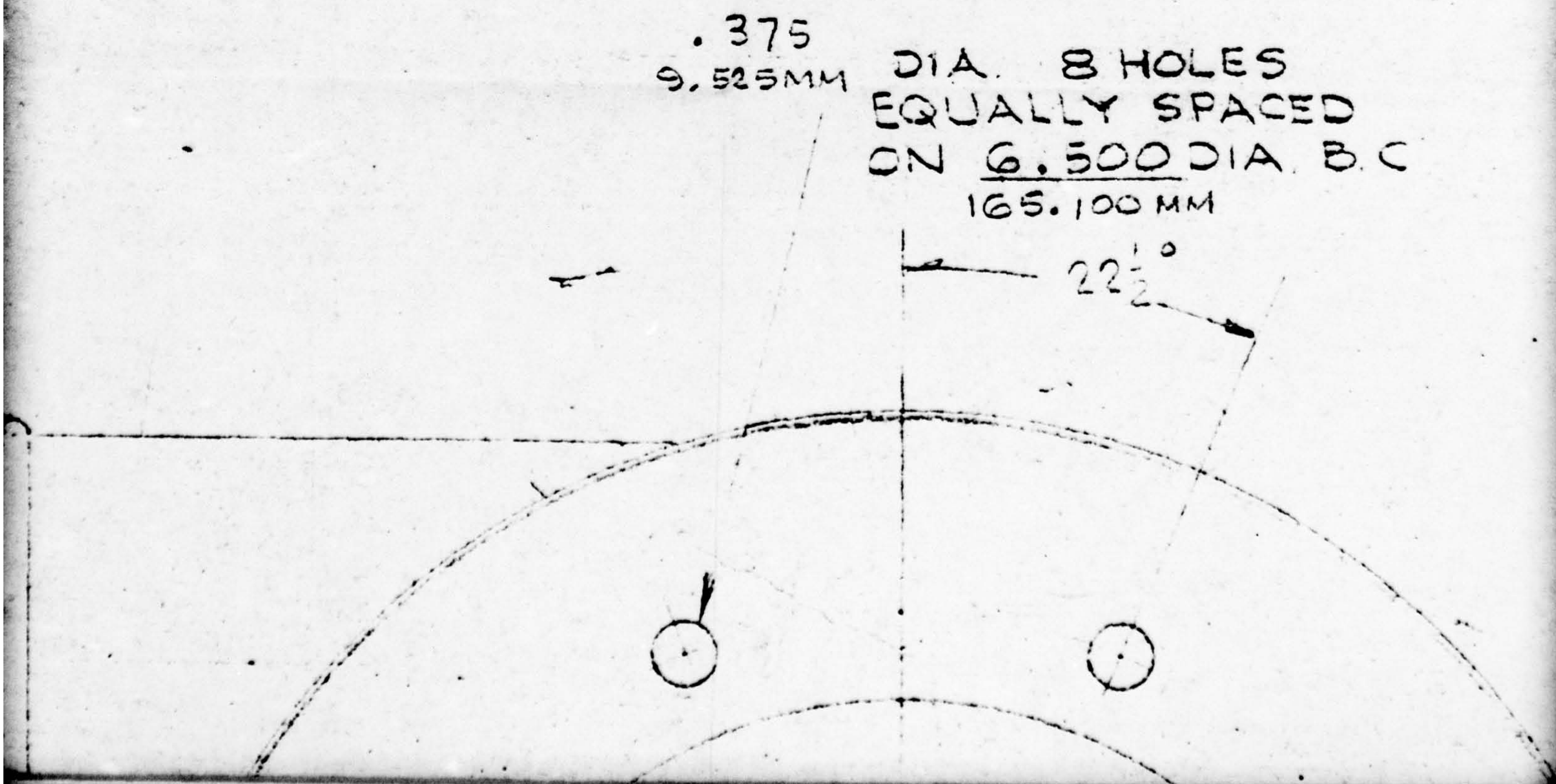
FIG. 16

| REVISIONS | | | | | | | |
|---|---|---|---|---|---|---|---|
| LTR | E.C.O. | DESCRIPTION | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| A | | REDRAWN & REVISED | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| B | | CHANGED POSITION OF AIR INLET. SHOWED ALL LEADS | R.J. | | | 9-9-78 | [illegible] |
| C | | DELETED COIL SUPPORT FLANGE. | A.S. | | | 11-1-78 | [illegible] |
| D | 39762 | ADDED METRIC EQUIVALENTS | R.J. | | | 5/2/79 | [illegible] |

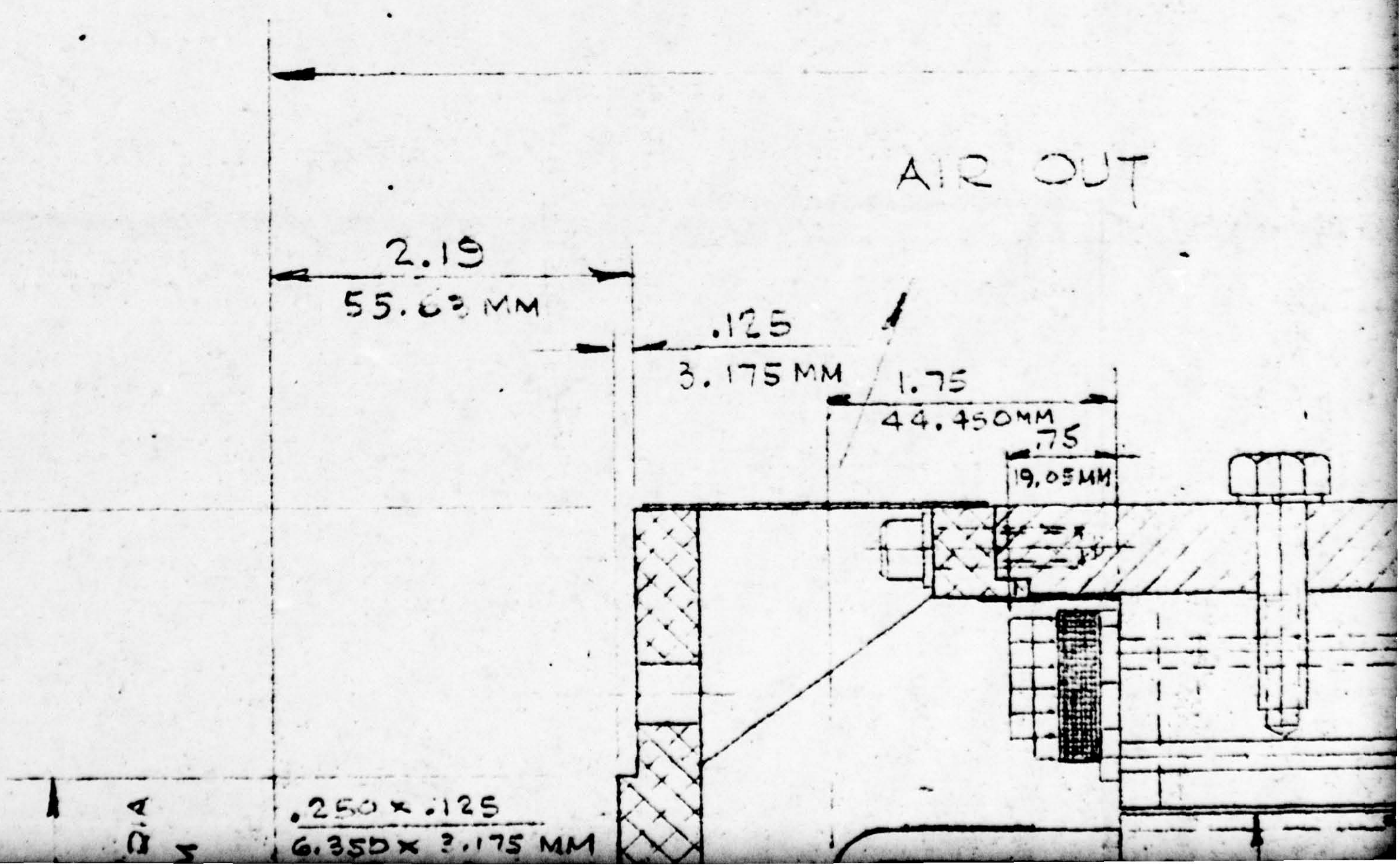
2

7

3

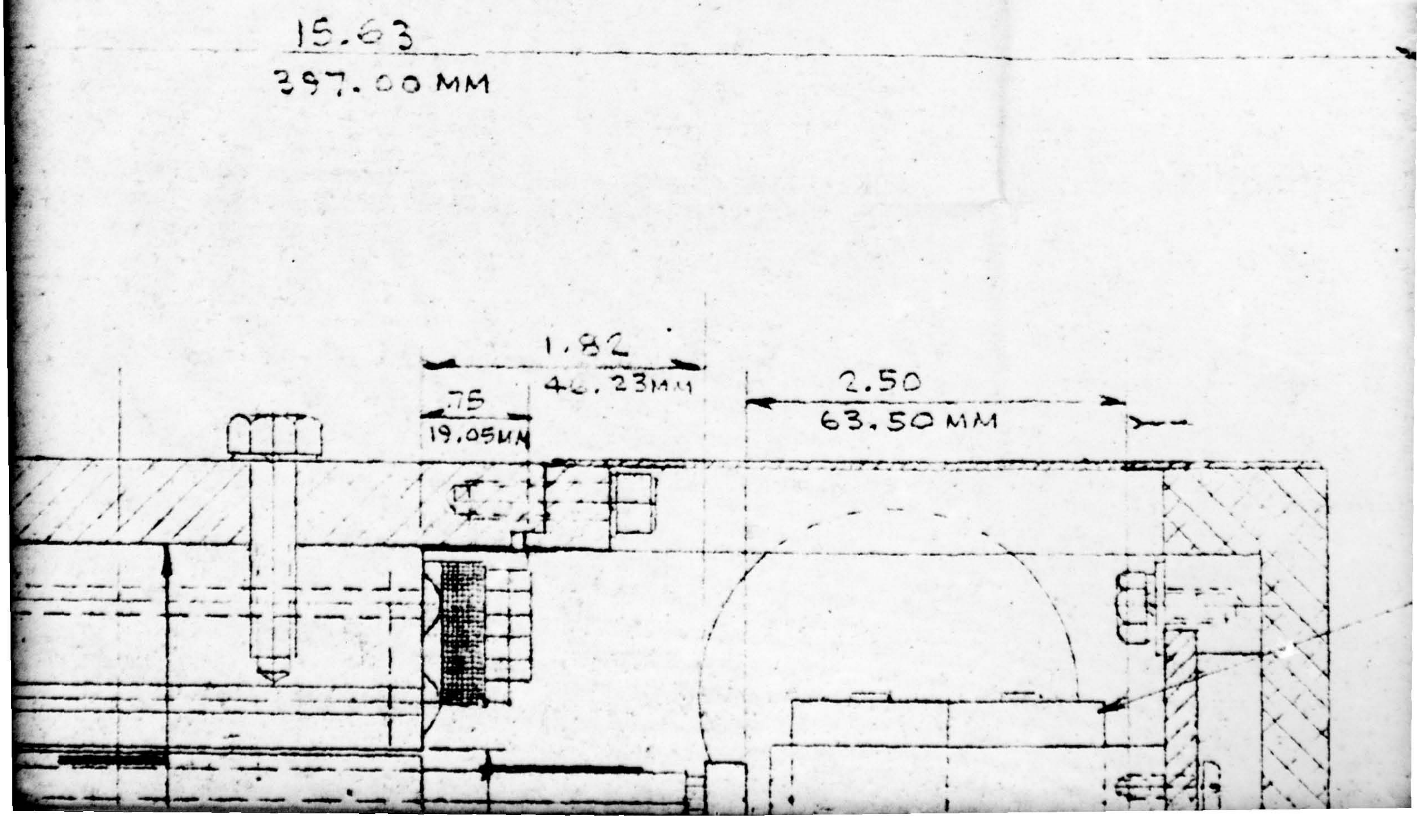

.375
9.525MM DIA. 8 HOLES
EQUALLY SPACED
ON 6.500 DIA. B.C
165.100 MM
22½°

4



AIR OUT
2.19
55.63 MM
.125
3.175 MM
1.75
44.450MM
.75
19.05MM
.250 x .125
6.350 x 3.175 MM

5



6

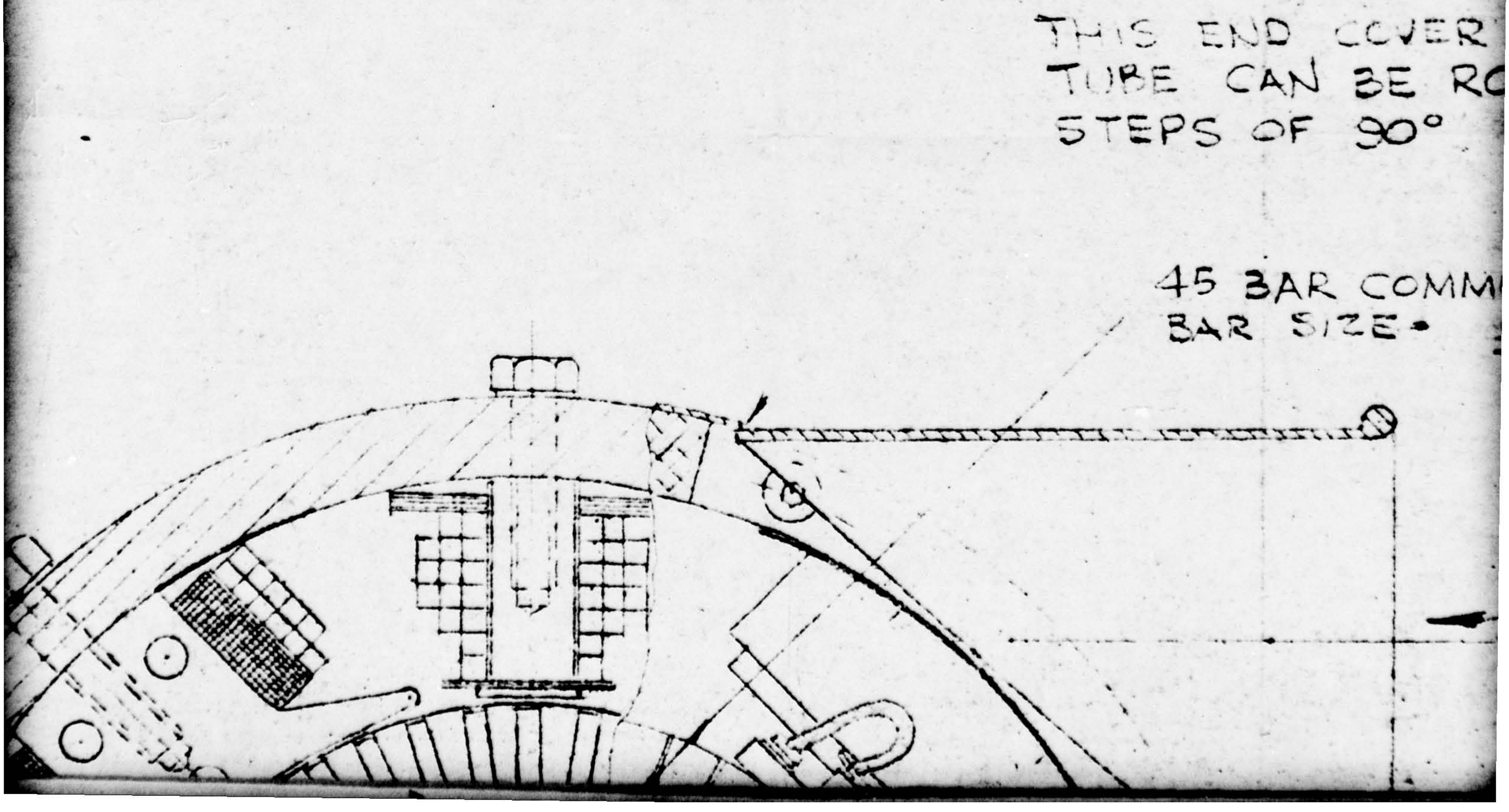
BRUSH SIZE

$\frac{.875}{22.225\,MM}$ LG × $\frac{1.000}{25.400\,MM}$ W × $\frac{.375}{9.525\,MM}$ TH.

RADIAL BALL

METRIC BALL BEARING

7

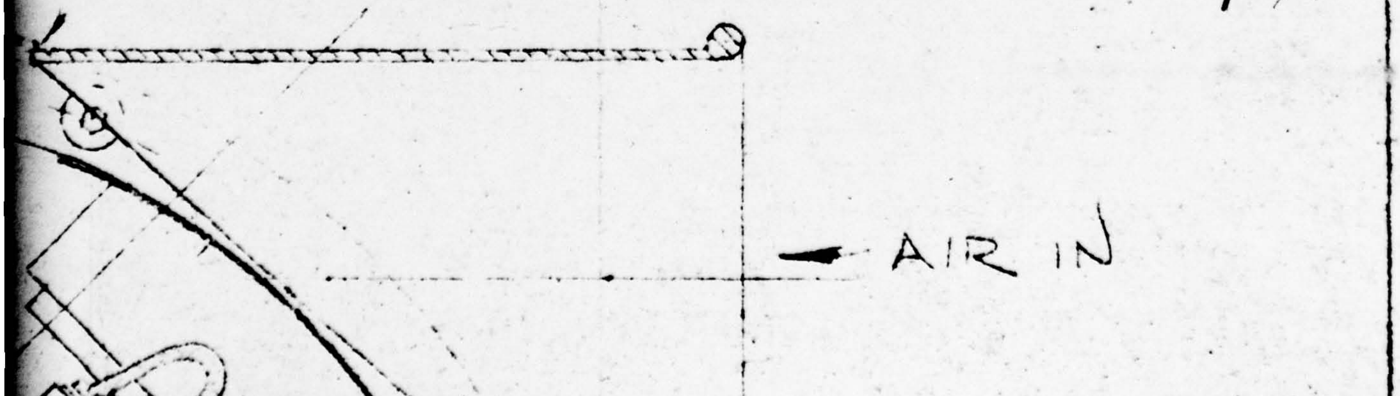


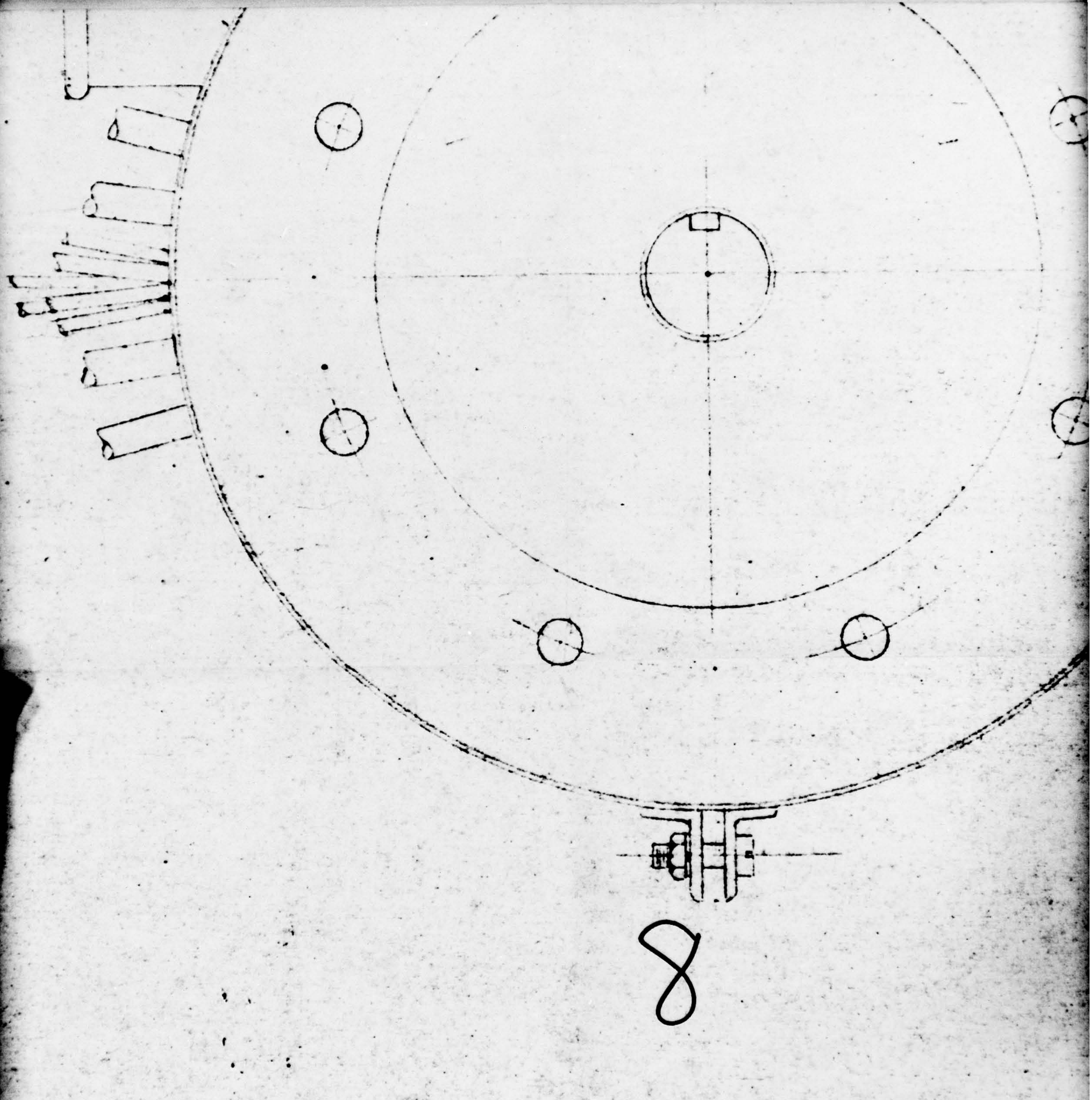
7

THIS END COVER WITH AIR INLET
TUBE CAN BE ROTATED IN
STEPS OF 90°

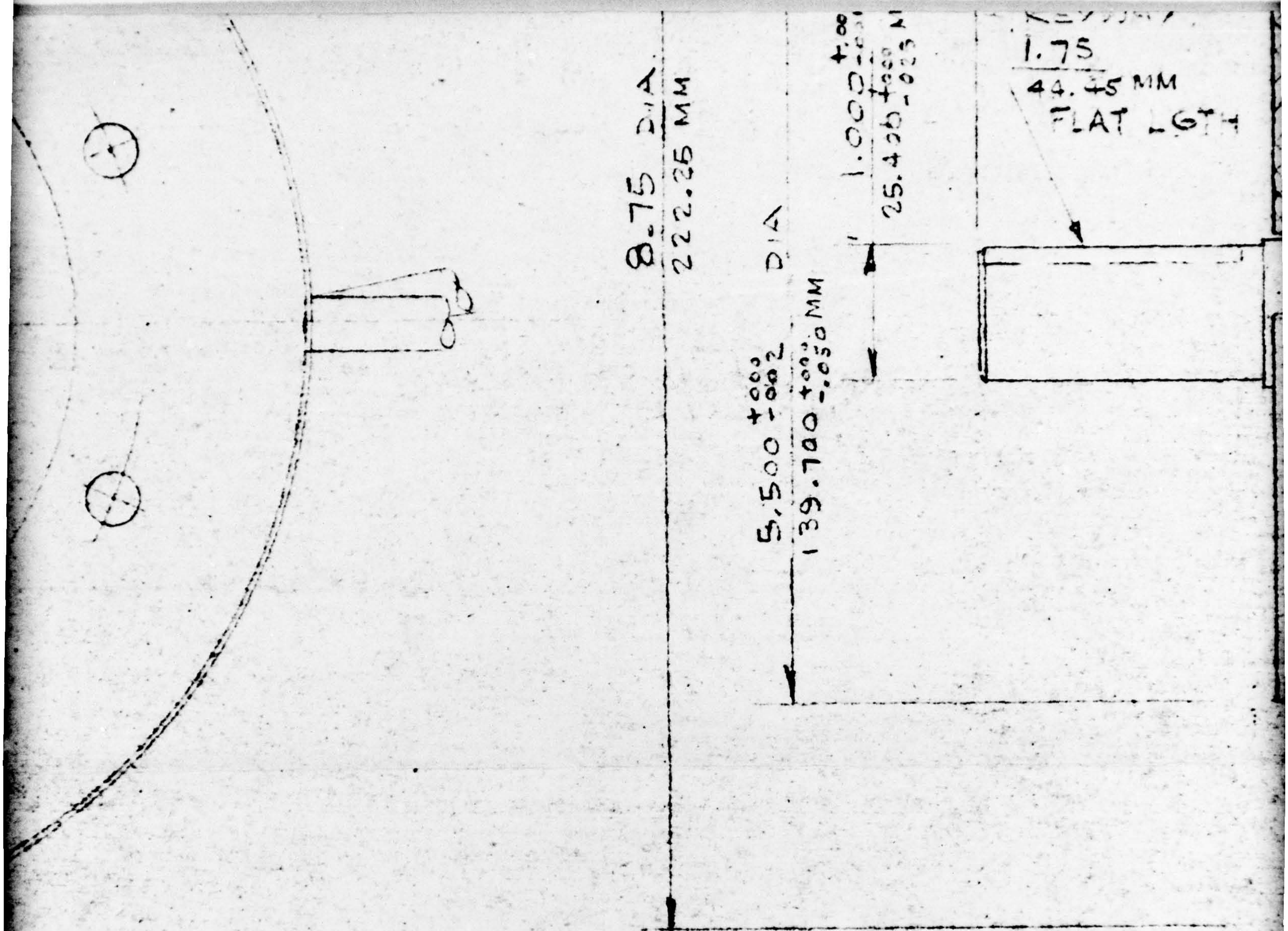
45 BAR COMMUTATOR
BAR SIZE = $\frac{.279}{7.087\,MM}$

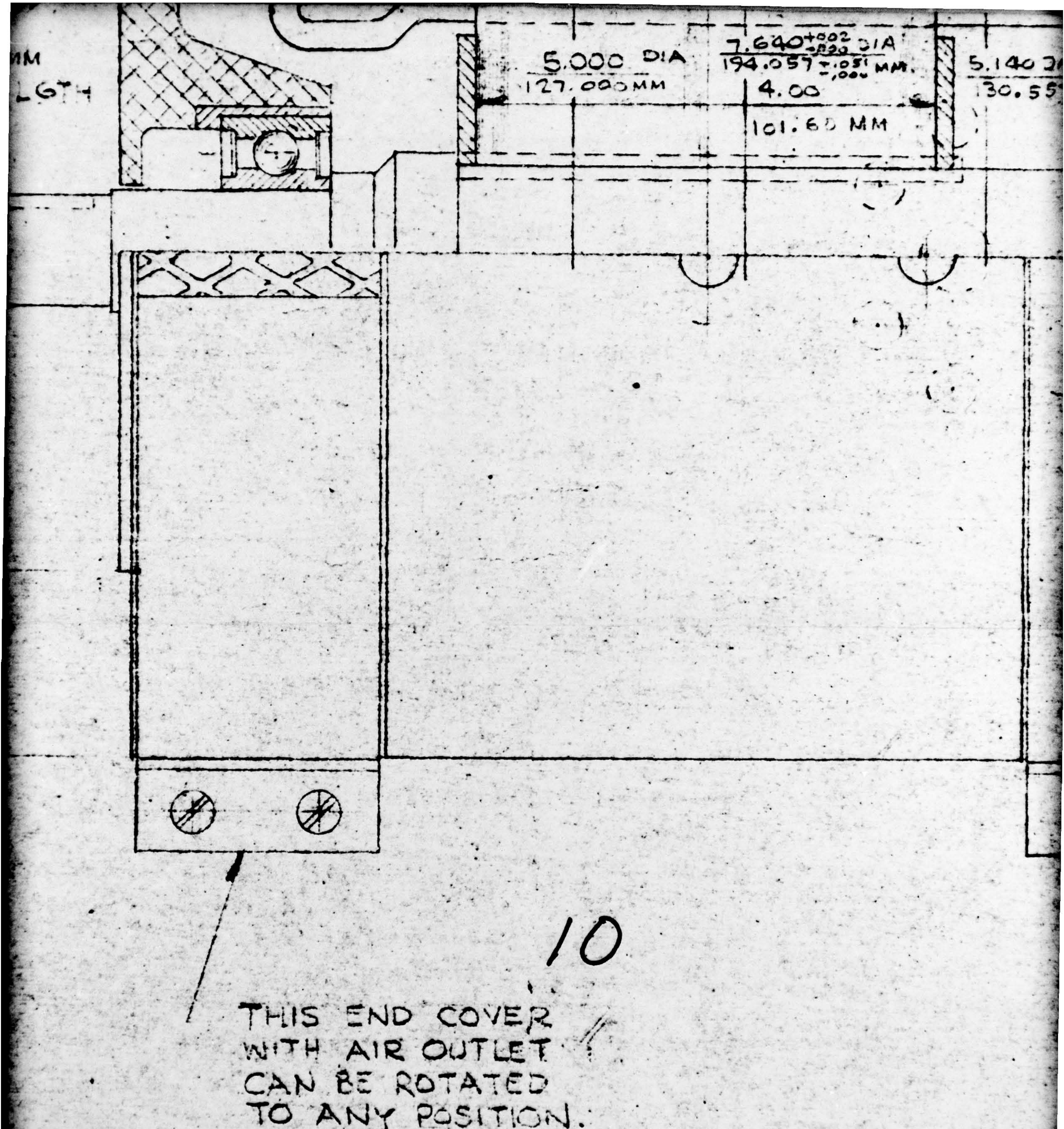
7-A

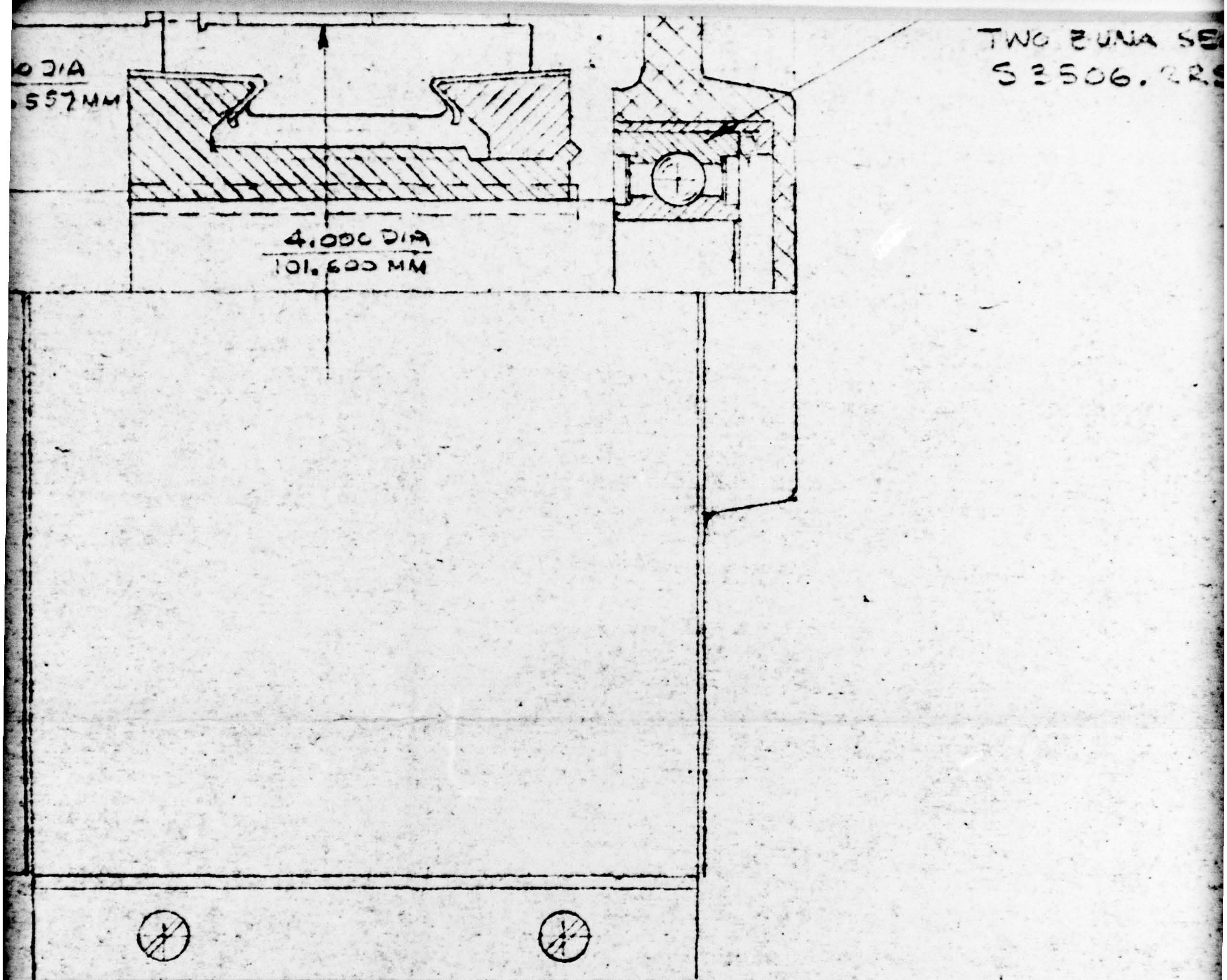




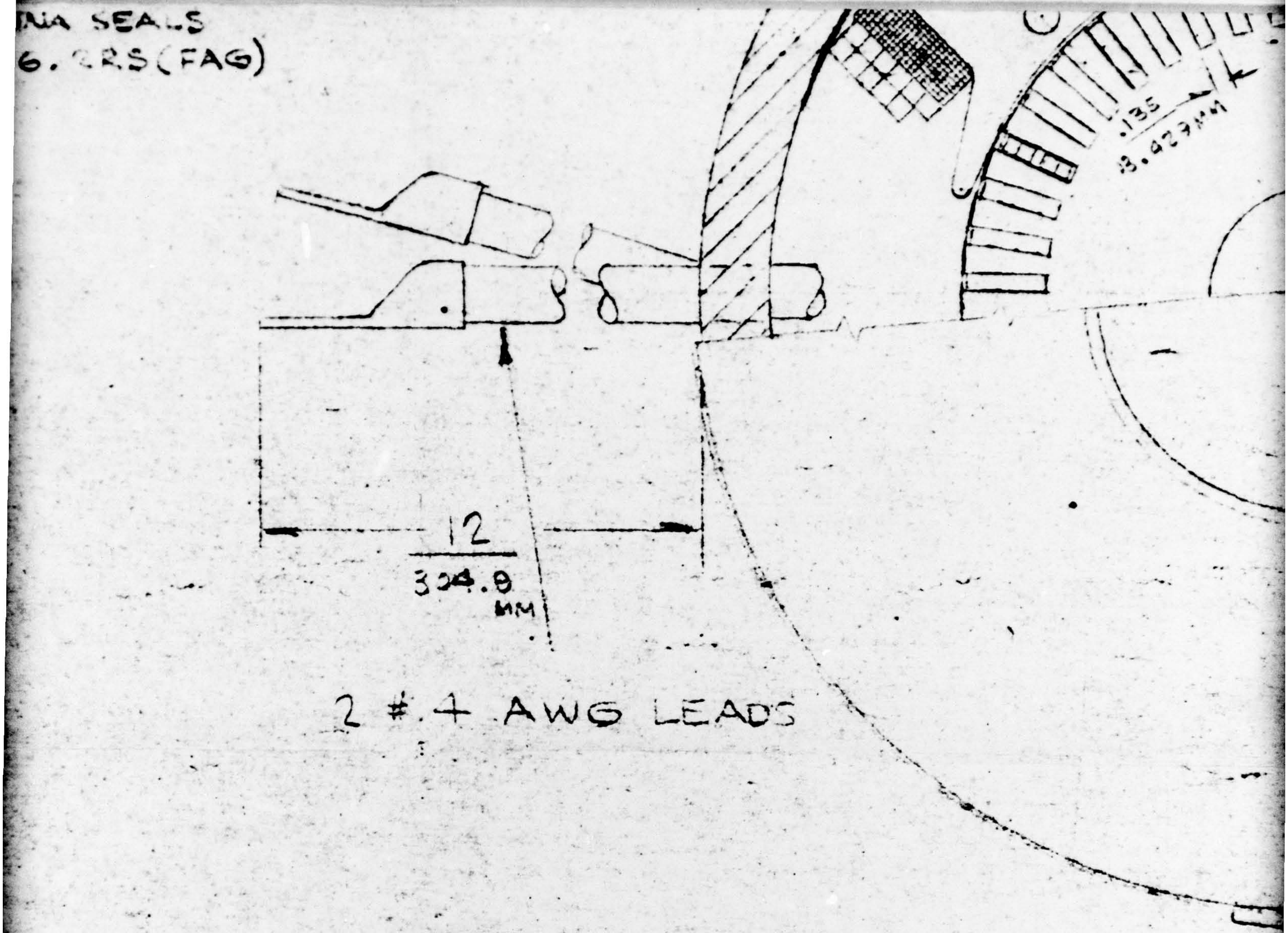
8


1.75
44.45 MM
FLAT LGTH
8.75 DIA
222.25 MM
5.500 +.000 -.002 DIA
139.700 +.000 -.050 MM
1.000
25.400


MM
LGTH
5.000 DIA
127.000 MM
7.640 +.002 -.000 DIA
194.057 +.051 -.000 MM
4.00
101.60 MM
5.140 D
130.55
THIS END COVER
WITH AIR OUTLET
CAN BE ROTATED
TO ANY POSITION.

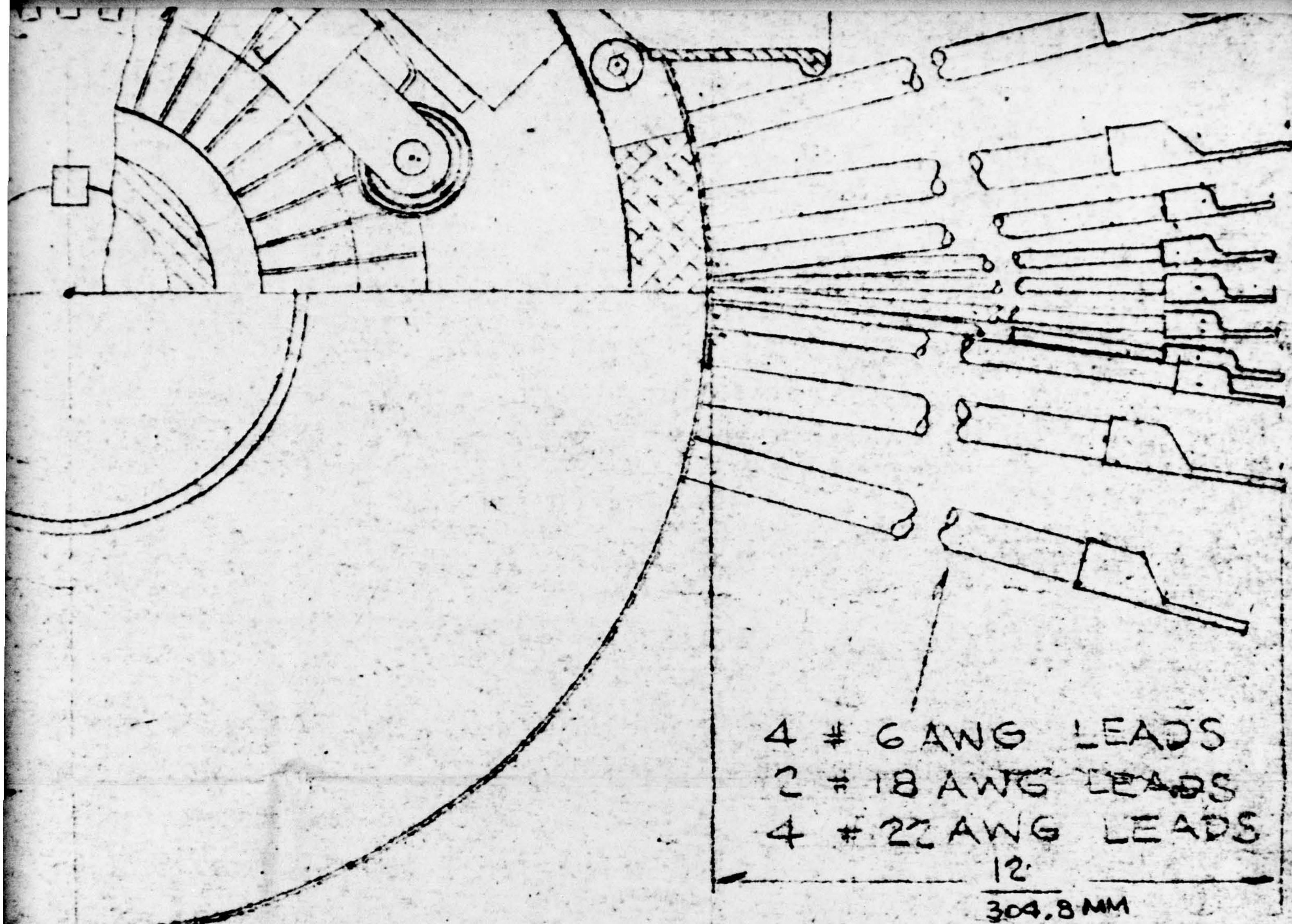



11




12

ALL DIMENSIONS ABOVE LINE
ARE IN INCHES & BELOW LINE
IN MILLIMETERS.




2 THERMAL SWITCHES ON INTERPOLES TO CLOSE AT $\frac{200°F}{93.3°C}$ AND $\frac{350°F}{192.2°C}$

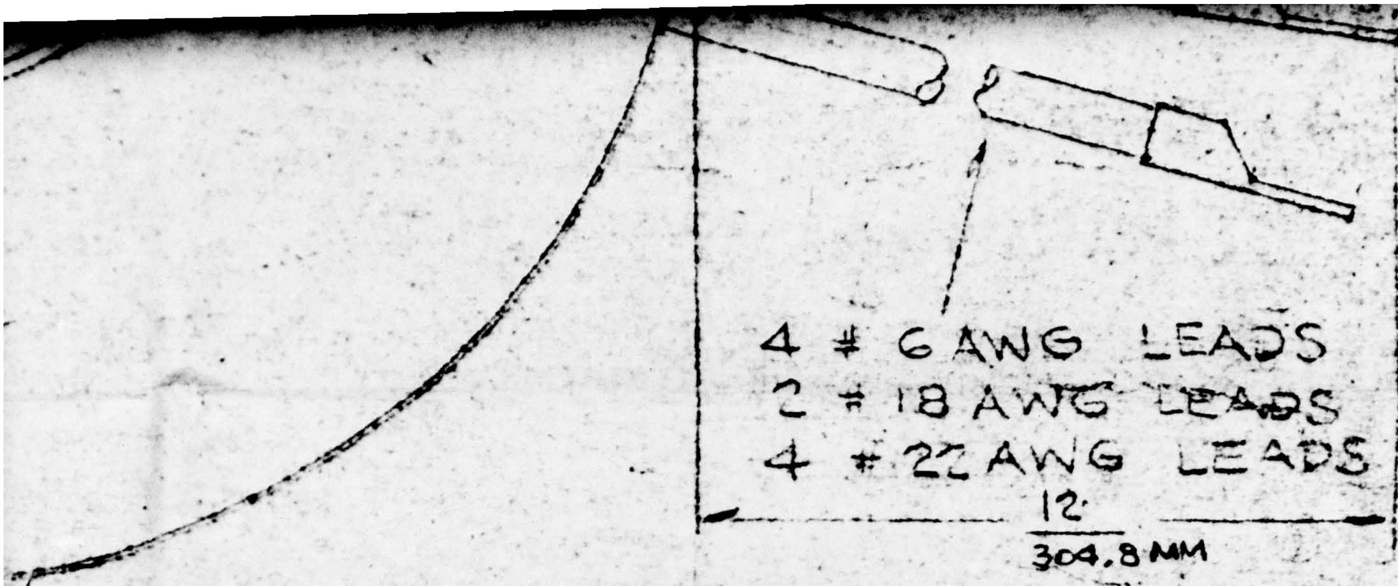
13

## RATING

10 HP 6000 RPM 48VDC CONTINUOUS
20 HP 3000 RPM 48VDC INTERMITTENT

WEIGHT CALCULATED - 90 LBS
40.823 KG

| FINAL USED ON 789G | | | BOGUE ELECTRIC MFG. CO. PATERSON, NEW JERSEY, U.S.A. |
|---|---|---|---|
| | BY | DATE | |
| LAYOUT | [illegible] | [illegible] | LAYOUT |
| DRAWN | | | |




2 THERMAL SWITCHES ON INTERPOLES TO CLOSE AT $\frac{200°F}{93.3°C}$ AND $\frac{350°F}{192.2°C}$

13

RATING

10 HP 6000 RPM 48VDC CONTINUOUS
20 HP 3000 RPM 48VDC INTERMITTENT

WEIGHT CALCULATED - 90 LBS
40.823 KG

| FIRST USED ON 7896 | | | BOGUE ELECTRIC MFG. CO. PATERSON, NEW JERSEY, U.S.A. |
|---|---|---|---|
| | BY | DATE | LAYOUT D C MOTOR |
| LAYOUT | | 7/14/79 | |
| DRAWN | | | |
| CHECKED | | | |
| ENGINEER | | 7/14/79 | |
| APPROVED | | | |

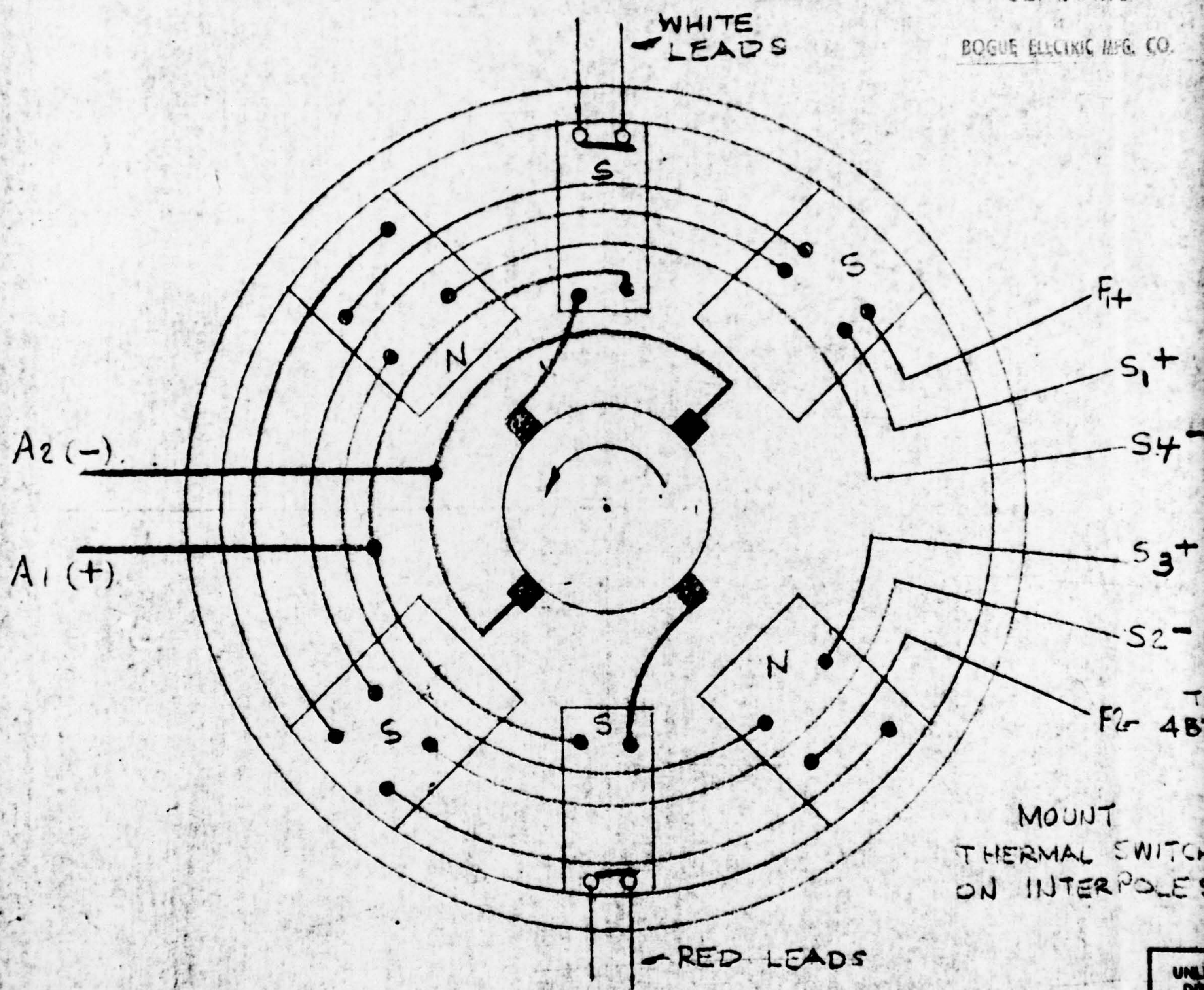
| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| | 07360 | [illegible] |

14

DATE OF ISSUE

SEP 28 1979

BOGUE ELECTRIC MFG. CO.




MOUNT THERMAL SWITCH ON INTERPOLE S

TH 4BT

UNLE DIM TOLERA ANGLE 2 PLAC 3 PLAC TO

MATERI

FINISH

ROTATION VIEWED FROM COMMUTATOR END

1

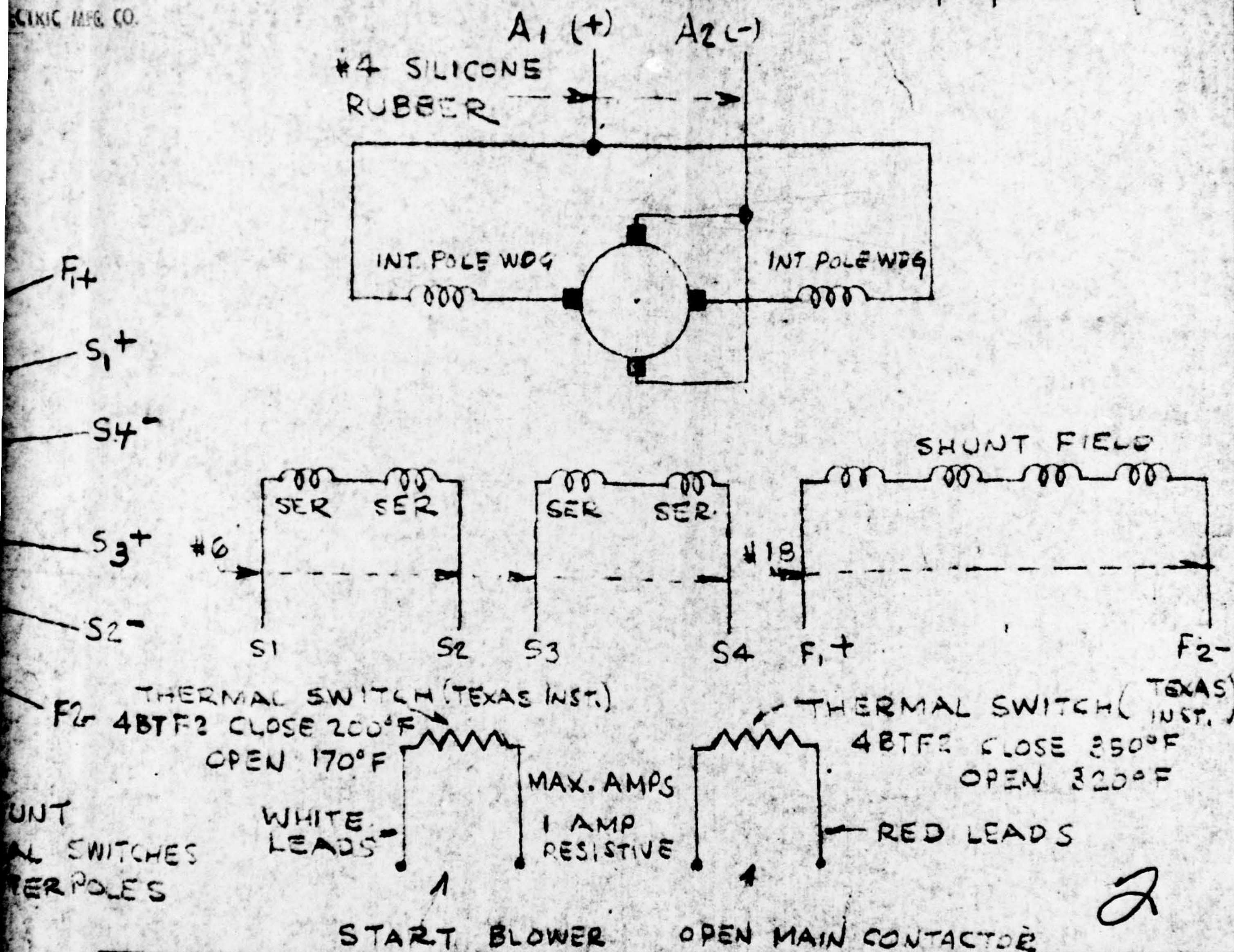
OF ISSUE

2 8 1979

ECTRIC MFG. CO.

| REVISIONS | | | | | | | |
|---|---|---|---|---|---|---|---|
| D.C.N. | ZONE | LTR | DESCRIPTION | DRFT | DATE | ENG | APPRVD |
| 39658 | | A | ADDED THERMAL SWITCHES TO DIAGRAM. INT. POLE WDG WAS COMM FIELD | FW | 2/20/79 | S.G. | [illegible] |
| 39720 | | B | WHITE LEADS WERE YELLOW LEADS. [illegible] A1 T(+) & A2 T(-) | FW | 4/4/79 | S.G. | [illegible] |

D




C

B

2

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTIONS ±
ANGLES ±
2 PLACE DECIMALS ±
3 PLACE DECIMALS ±
℄ TO ℄ HOLES ±

MATERIAL

FINISH

FIRST USED ON 7896

| | BY | DATE |
|---|---|---|
| DRAWN | FW | 2/27/78 |
| CHECKED | | |
| ENGINEER | S.G. | 2/27/78 |
| APPROVED | [illegible] | |

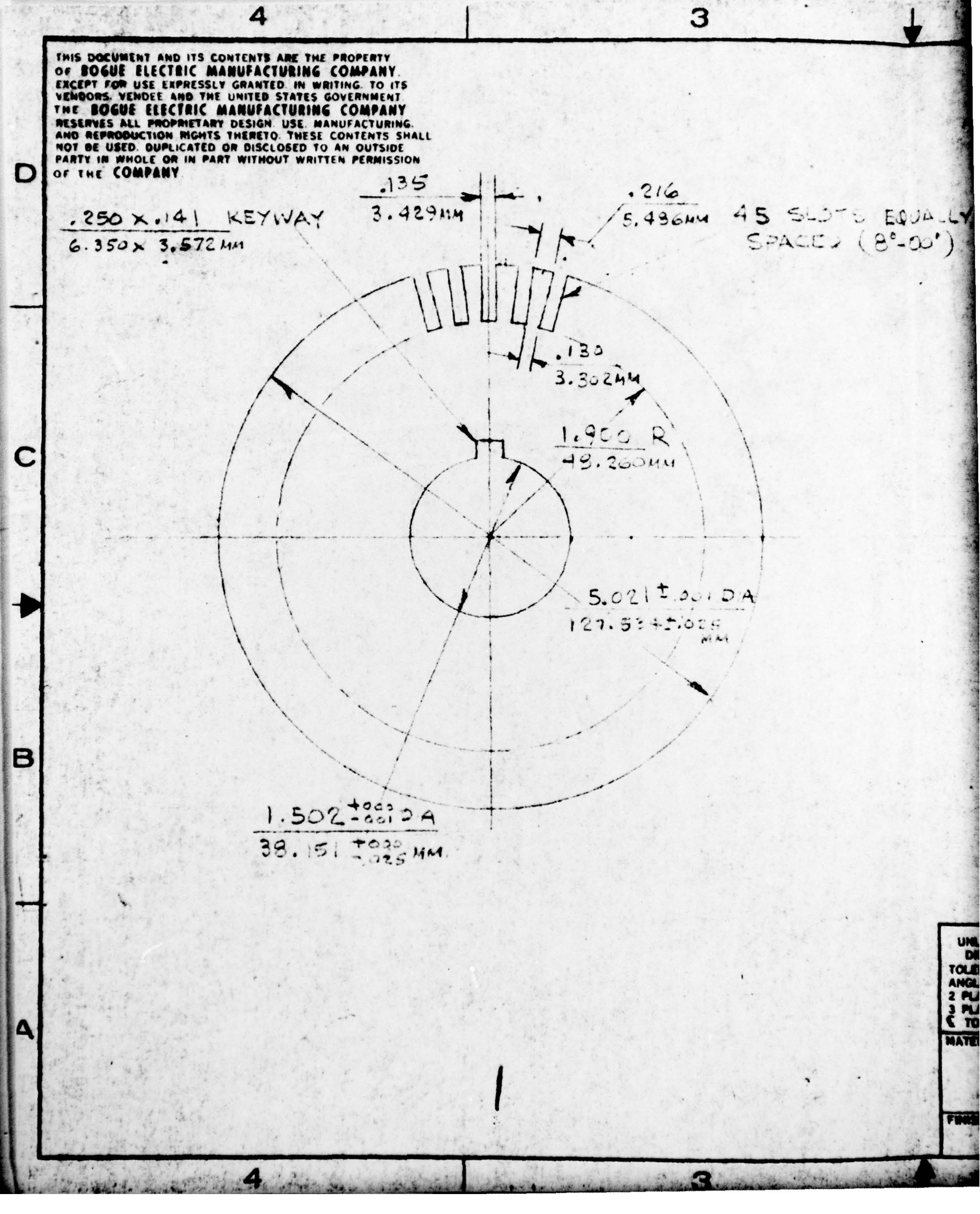
**BOGUE ELECTRIC MFG. CO.**
PATERSON, NEW JERSEY, U.S.A.

# CONNECTION DIAGRAM

| SIZE | CODE IDENT NO. | DRAWING NO. | REV |
|---|---|---|---|
| B | 07880 | B 43079 | B |

SCALE | WT. | SHEET

A


4
3
D
C
B
A
.135
3.429MM
.216
5.496MM
45 SLOTS EQUALLY SPACED (8°-00')
.250 x .141 KEYWAY
6.350 x 3.572MM
.130
3.302MM
1.900 R
48.260MM
5.021 ±.001 DIA
127.534 ±.025 MM
1.502 +.000 -.001 DIA
38.151 +.000 -.025 MM
1
UNL
DI
TOLE
ANGL
2 PLA
3 PLA
TO
MATE
FINIS

| REVISIONS | | | | | | | |
|---|---|---|---|---|---|---|---|
| D.C.N. | ZONE | LTR | DESCRIPTION | DRFT | DATE | ENG | APPRVD |
| | | A | 45 SLOTS @ 8°.00' WAS 49 SLOTS @ 7°-20'-49.8' - 1.900R WAS 1.996R .135 WAS .125 - .216 WAS .197 .130 WAS .131 - SLOT DIE WAS A 5020 | FW | 9/12/79 | Sr. | |
| 39742 | | B | ADDED METRIC DIMENSIONS | FW | 9/2/79 | | |

S EQUALLY
(8°-00')

BLANKING DIE - A 2849 (206)
SLOT DIE A 50655 (T-7692)

MATERIAL

PART 1 - #29 GA M-19-C5 STEEL $\frac{.014}{.356MM}$

DATE OF ISSUE
SEP 28 1979
BOGUE ELECTRIC MFG. CO

$\frac{\text{INCHES}}{\text{MILLIMETERS}}$

2

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTIONS ±
ANGLES ±
2 PLACE DECIMALS ±
3 PLACE DECIMALS ±
℄ TO ℄ HOLES ±
MATERIAL
FINISH

FIRST USED ON 7896

| | BY | DATE |
|---|---|---|
| DRAWN | FW | 7/27/78 |
| CHECKED | | |
| ENGINEER | | 11/27/78 |
| APPROVED | | |

**BOGUE ELECTRIC MFG. CO.**
PATERSON, NEW JERSEY, U.S.A.

ROTOR LAMINATION

| SIZE | CODE IDENT NO. | DRAWING NO. | REV |
|---|---|---|---|
| B | 07860 | B 43080 | B |

SCALE | WT. | SHEET

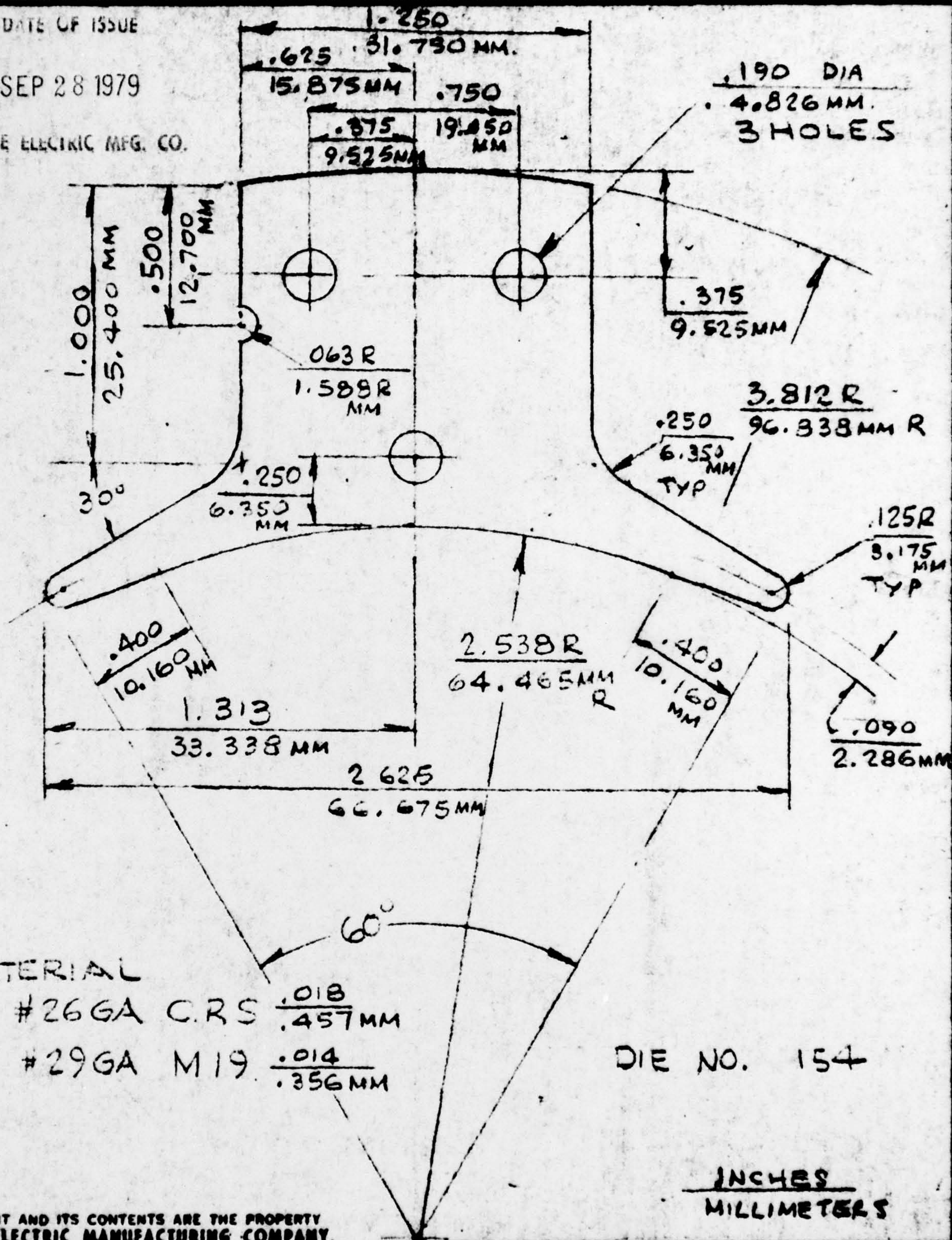
| CHANGE NOTICE NO. | NO. | DATE | REVISION | REV. |
|---|---|---|---|---|
| 39762 | A | [illegible] | [illegible] | A |

**A-2300**

DATE OF ISSUE

SEP 28 1979

BOGUE ELECTRIC MFG. CO.




.MATERIAL

PT-1 #26GA C.R.S $\frac{.018}{.457\text{MM}}$

PT2 #29GA M19 $\frac{.014}{.356\text{MM}}$

DIE NO. 154

INCHES / MILLIMETERS



[redacted]

TOLERANCES:
Unless Otherwise Specified
Fractions ± Decimals ±

**BOGUE ELECTRIC MANUFACTURING CO.**
PATERSON, N.J.

POLE LAMINATION

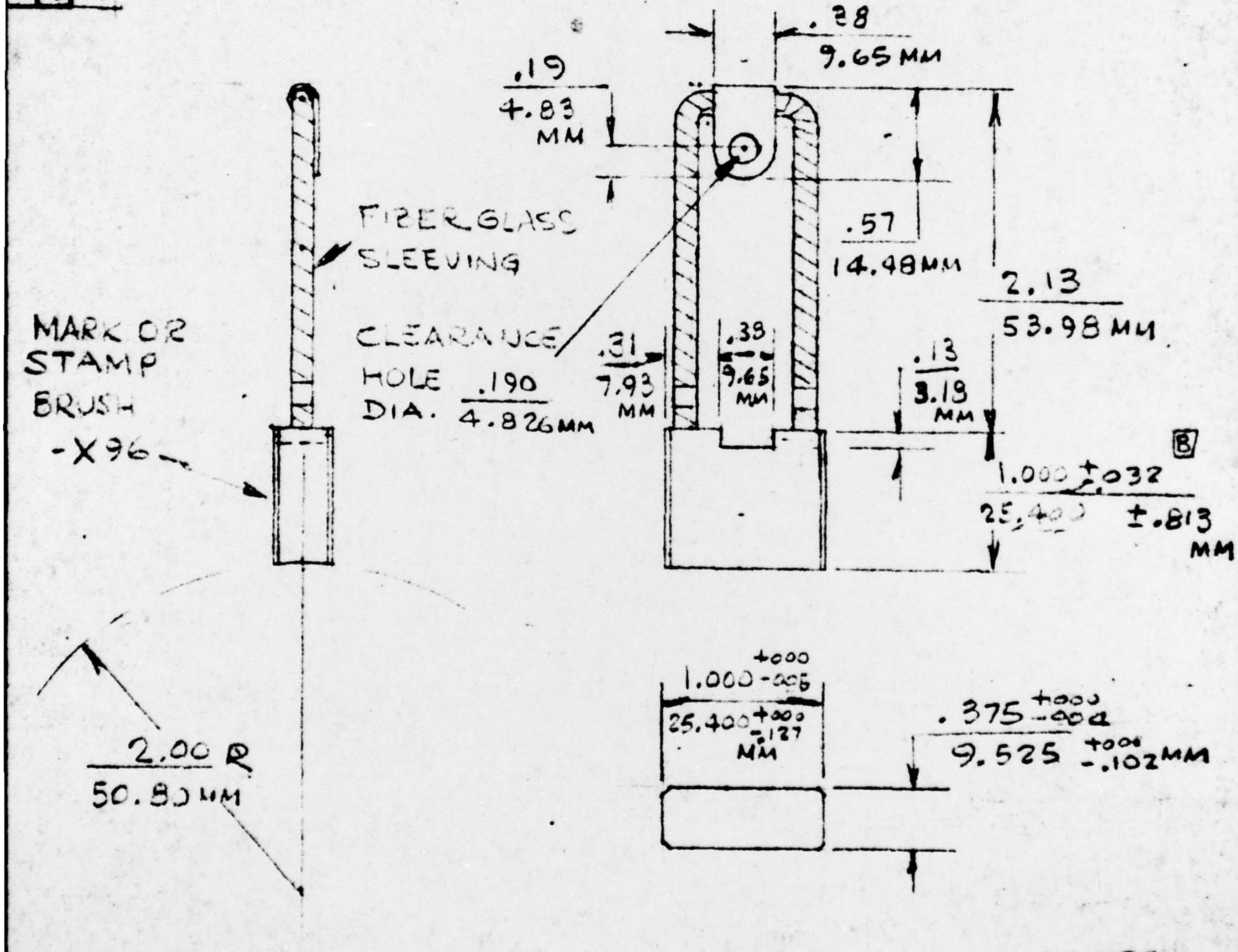
DR. BY: [illegible] 9/27/79
APPROVED S.G. [illegible]
SCALE: 2X APP'D [illegible]

A-2300 | A

| NO. | NO. | DATE | REVISION |
|---|---|---|---|
| 39762 | A | 9/1/79 | MADE METRIC D. MAY |
| 39884 | B | 8/16/79 | 1.000 WAS .875 S. G. |

MATERIAL
A53200-X96

DATE OF ISSUE
SEP 28 1979
BOGUE ELECTRIC MFG.




INCHES
MILLIMETERS



**BOGUE ELECTRIC MANUFACTURING CO.**
PATERSON, N.J.

BRUSH

TOLERANCES:
Unless Otherwise Specified
Fractions ±   Decimals ±

DR. BY: JW 7/27/79
APPROVED S. G 7/31/79
SCALE: Approved LWS

A-54305 REV B

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| Mr. Edward Beyma<br>Transportation Energy Conservation Division<br>Department of Energy<br>20 Massachusetts Avenue, NW<br>Washington, DC 20545 | 5 |
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USAMERADCOM (Continued)

| | |
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| Commander<br>ATTN: Office of Patent Counsel<br>USAMERADCOM, DRDME-L<br>Fort Belvoir, VA 22060 | 1 |
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| Commander<br>ATTN: Technical Library<br>USAMERADCOM, DRDME-WC<br>Fort Belvoir, VA 22060 | 2 |